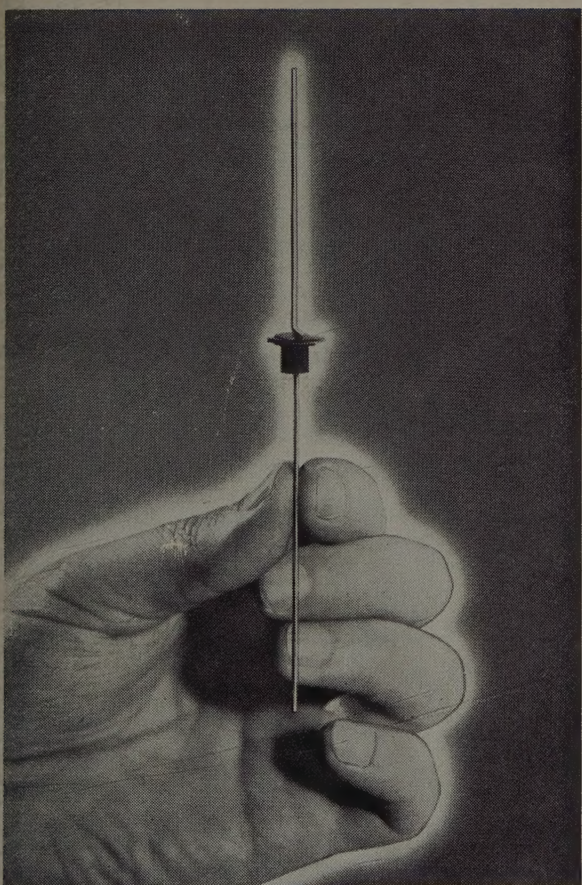
APRIL · 1955

Proceedings OF THE IRE

A Journal of Communications and Electronic Engineering

Volume 43 Number 4

SILICON RECTIFIERS



Bogue Electric Manufacturing Co.

The rapid strides which recently have been made in the field of solid state materials and devices are typified by the development of the silicon power rectifier shown above.

PART I

TABLE OF CONTENTS INDICATED BY BLACK-AND-WHITE MARGIN, FOLLOWS PAGE 80A

The Institute of Radio Engineers

choose from this complete line of

MINIATURE PULSE TRANSFORMERS

Type 10Z
tubular pulse transformer

Type 15Z
miniature bathtub pulse transformer

Type 20Z
drawn-shell bathtub pulse transformer

Type 40Z
plug-in pulse transformer

NOW YOU CAN CHOOSE from eighteen standard pulse transformers in four major construction styles, all in quantity production at Sprague. The standard transformers covered in the table below offer a complete range of characteristics for computer circuits, blocking oscillator circuits, memory array driving circuits, etc.

These hermetically sealed units will meet such stringent military specifications as MIL-T-27, and operate at temperatures up to 85°C. Special designs are available for high acceleration and high ambient temperature operation. In addition, the electrical counterparts of each transformer can be obtained in lower cost housings designed for typical commercial environment requirements.

Complete information on this high-reliability pulse transformer line is provided in Engineering Bulletin 502A, available on letterhead request to the Technical Literature Section, Sprague Electric Company, 235 Marshall Street, North Adams, Massachusetts.

ELECTRICAL CHARACTERISTICS OF SPRAGUE PULSE TRANSFORMERS

Type No.	Turns Ratio	Pulse Width μ seconds	Rise Time μ seconds	Primary Inductance	Leakage Inductance	Repetition Rate	Load and Output	Typical Applications
10Z1	5:1	0.1	0.04	200 μH	5 μH	1 to 2 MC	15 volts 100 ohms	Used in digital computer circuitry for impedance matching and inter-stage coupling. Pulses are of sine wave type.
10Z2	4:1	0.07	0.03	200 μH	20 μH	1 to 2 MC	20 volts 100 ohms	
10Z3	1:1	0.07	0.03	125 μH	12 μH	1 to 2 MC	20 volts 200 ohms	
10Z4	3:1	0.07	0.03	160 μH	15 μH	1 to 2 MC	20 volts 100 ohms	
10Z6	4:1	0.1	0.04	200 μH	6 μH	1 to 2 MC	17 volts 100 ohms	
10Z12	1:1	0.25	0.02	200 μH	2 μH	12KC	100 volts	Blocking Oscillator
10Z13	1:1	0.33	0.07	240 μH	2 μH	2KC	50 volts	Blocking Oscillator
10Z14	7:1:1	0.50	0.05	1.2 mH	20 μH	1MC	25 volts	Impedance Matching
15Z1	3:1	5.0	0.04	7.5 mH	22 μH	10 KC	10 volts 100 ohms	Impedance Matching and Pulse Inversion
15Z2	2:1	0.5	0.07	6 mH	15 μH		40 volts	Blocking Oscillator
15Z3	5:1	10.0	0.04	12 mH	70 μH	10 KC	10 volts	Impedance Matching
15Z4	1:1.4	6.0	0.1	16 mH	15 μH	0.4 KC	15 volts	Blocking Oscillator
20Z1	5:5:1 Push-Pull	1.5	0.25	4.0 mH	0.3 MH		5 volts 10 ohms	Memory Core Current Driver
20Z3	6:1	1 to 4	0.22	18 mH	0.8 MH	250 KC (max.)	21 volts 200 ohms	Current Driver
20Z4	6:1:1	1 to 7	0.25	55 mH	0.3 MH	50 KC (max.)	22 volts 400 ohms	Current Driver and Pulse Inversion
20Z5	3.3:3.3:1 Push-Pull	2.4	0.2	2.8 mH	0.2 MH		2.5 volts 6 ohms	Memory Core Current Driver
20Z6	11:1	6.0	0.2	90 mH	0.2 MH	50 KC (max.)	10 volts 75 ohms	Current Transformer
40Z1	7:1:1	0.50	0.05	1.2 mH	20 μH	1 MC	25 volts	Impedance Matching

Sprague, on request, will provide you with complete application engineering service for optimum results in the use of pulse transformers.

SPRAGUE® WORLD'S LARGEST CAPACITOR MANUFACTURER

Export for the Americas: Sprague Electric International Ltd., North Adams, Mass. CABLE: SPREXINT

Meetings with Exhibits

As a service both to Members and the industry, we will endeavor to record in this column each month those meetings of IRE, its sections and professional groups which include exhibits.

Δ

April 15-16, 1955
Ninth Annual Spring Technical Conference, Cincinnati Section, IRE, Engineering Society of Cincinnati Bldg., Cincinnati, Ohio
Exhibits: Mr. Clyde G. Haehnle, Crosley Broadcasting Corp., 140 West Ninth St., Cincinnati 2, Ohio

April 27-29, 1955
Seventh Regional Technical Conference & Trade Show, Hotel Westward Ho, Phoenix, Ariz.
Exhibits: Mr. George McClarathan, 509 East San Juan Cove, Phoenix, Ariz.

May 9-11, 1955
National Conference on Aeronautical Electronics, Biltmore Hotel, Dayton, Ohio.
Exhibits: Mr. William Klein, 1472 Earlham Drive, Dayton, Ohio

May 18-20, 1955
National Telemetering Conference, Morrison Hotel, Chicago, Ill.
Exhibits: Mr. Kipling Adams, General Radio Company, 920 S. Michigan Ave., Chicago, Ill.

June 2-3, 1955
I.R.E. Materials Symposium, Convention Hall, Philadelphia, Pa.
Exhibits: Mr. Merritt A. Rudner, United States Gasket Co., 611 North Tenth St., Camden 1, N.J.

Aug. 24-26, 1955
Western Electronic Show & Convention, Civic Auditorium, San Francisco, Calif.
Exhibits: Mr. Mal Mobley, 344 N. La-Brea, Los Angeles 36, Calif.

Sept. 12-16, 1955
Tenth Annual Instrument Conference & Exhibit, Shrine Exposition Hall & Auditorium, Los Angeles, Calif.
Exhibits: Mr. Fred J. Tabery, 3443 So. Hill St., Los Angeles 7, Calif.

October 3-5, 1955
National Electronics Conference, Sherman Hotel, Chicago, Ill.
Exhibits: Mr. G. J. Argall, c/o DeVry Technical Institute, 4141 Belmont Ave., Chicago 41, Ill.

Note on Professional Group Meetings: Some of the Professional Groups conduct meetings at which there are exhibits. Working committeemen on these groups are asked to send advance data to this column for publicity information. You may address these notices to the Advertising Department, and of course listings are free to IRE Professional Groups.

Industrial Engineering Notes *

FCC Actions

The Federal Communications Commission recently finalized, with certain changes, its proposal in Docket 11031 and amended part 18 of its Rules Governing Industrial, Scientific and Medical Services by redefining "miscellaneous equipment" to include apparatus that applies radio frequency energy to materials to produce physical, biological or chemical changes but which does not involve communications or the use of radio receiving equipment. The new rules became effective on March 1. A new subpart classifies ultrasonic equipment as a special type of miscellaneous equipment which includes any apparatus generating radio frequency energy on frequencies above 20 kc and utilizing that energy to excite or drive an electro-mechanical transducer for the production and transmission of ultrasonic energy for industrial, scientific, medical or other purposes. New technical requirements are established and a type approval and certification procedure is provided. . . . **Following comments filed by RETMA with the Federal Communications Commission in Docket 9288, in which it was pointed out that many imported receivers do not comply with the proposed restrictions on spurious radiation, the FCC directed the following letter to all known importers of FM and TV receivers:** "Your attention is invited to the attached Notice of Proposed Rule Making (Docket 9288) which proposes limits of oscillator radiation for FM and television broadcast receivers. The radio manufacturing industry in the United States has been cooperating with this Commission in a program of reduction of oscillator radiation. It has come to the attention of the Commission that foreign made receivers imported into this country may be in violation of standards which may be adopted by the Commission and that, in such event, steps toward the enforcement of the Commission's rules may be necessary. It is suggested that you give this problem your earnest consideration and convey this information to the manufacturers of any foreign receivers which you may be importing. The Commission will welcome any comments you may wish to submit in connection with this matter."

Industry Statistics

The Radio-Television-Manufacturers Association of Canada has announced the projected production of 207,256 television sets in Canada during the months of January, February and March. December production amounted to 93,928 sets and sales of 89,078 units were reported. A total of 593,856 television receivers were produced during the year 1954, with sales for the year reported to be 619,428 receivers by the Canadian RTMA. . . . **The pro-**

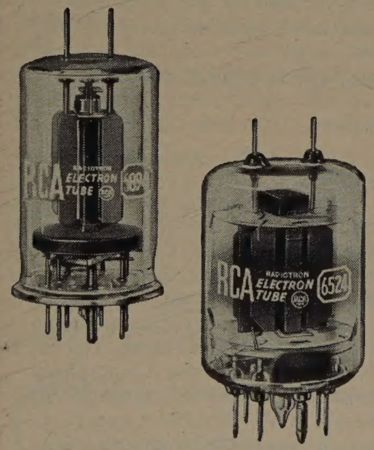
(Continued on page 14A)

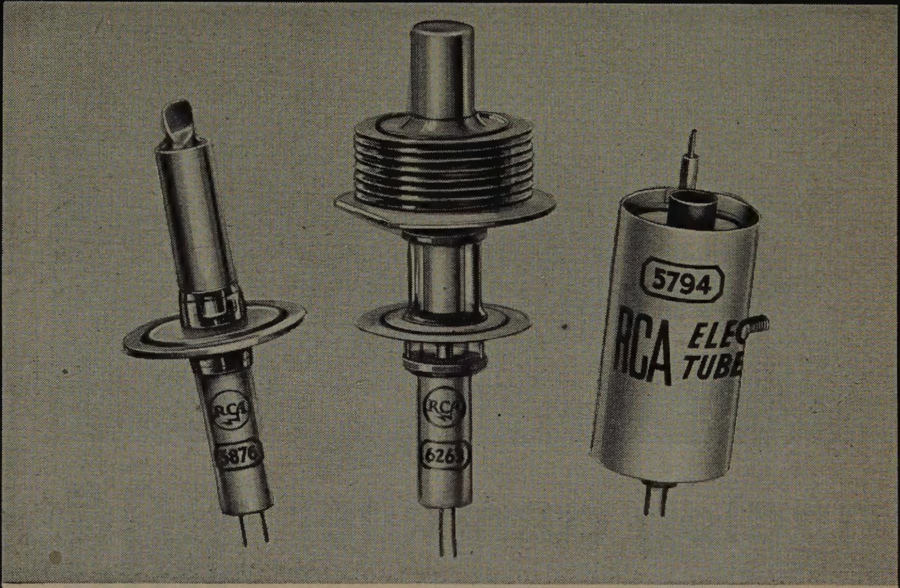
* The data on which these Notes are based were selected by permission from *Industry Reports*, issues of January 24, 31, and February 7, published by the Radio-Electronics-Television Manufacturers Association, whose helpfulness is gratefully acknowledged.

DESIGNERS

RCA SMALL-SIZED UHF POWER TUBES

Well-suited for fixed and mobile uhf applications up to 470 mc, these unique twin beam power tubes offer designers unusual advantages—as balanced push-pull rf power amplifiers or frequency triplers. RCA-6524 delivers approx. 20 watts (ICAS) in push-pull class C amplifier service—at 462 mc! Max. plate dissipation: 25 w (ICAS). RCA-5894 delivers approx. 55 watts (CCS) at 470 mc. Max. plate dissipation: 40 watts (CCS).





RCA "PENCIL" TUBES FOR UHF

Available in a choice of types for uhf applications, RCA "Pencil Tubes" are designed to have minimum transit time, low lead inductance, and low interelectrode capacitances. Features include small size, light weight, low heater wattage, and good thermal stability. RCA-6263 with external plate radiator is intended for rf power amplifier and oscillator services; 6264 is like the 6263 but is well-suited for frequency-multiplier service. Additional RCA "Pencil Tubes" include 5674, 5794, 5876, 6173.

NEW 5" PROJECTION KINESCOPE (FOR CLOSED-CIRCUIT INDUSTRIAL TV)

Providing a clear, bright, projected picture about eight feet by six feet when used with a suitable reflective optical system, the RCA-5AZP4 is especially useful for closed-circuit industrial TV. Contributing to the brightness of the "auditorium-size" picture of high-efficiency, aluminized screen having very good color stability under varying conditions of screen current, and an unusually high operating ultor voltage (40,000 volts max.) for a tube of this type.

For technical information, write—specifying tube types in which you are interested—to RCA, Commercial Engineering, Section D35R, Harrison, N.J., or call your RCA Representative:

EAST______HUmboldt 5-3900
744 Broad St.
Newark, N. J.

MIDWEST______WHitehall 4-2900
589 E. Illinois St.
Chicago 11, Ill.

WEST______MAdison 9-3671
420 S. San Pedro St.
Los Angeles 13, Calif.

RADIO CORPORATION of AMERICA
TUBE DIVISION HARRISON, N. J.

Industrial Engineering Notes

(*Continued from page 8A*)

duction of television receivers during 1954 was at the second highest point on record. Over 7.3 million TV sets and 10.4 million radios were produced during the year. Total television set production was reported as 7,346,715 units during the year, compared with 7,215,827 sets manufactured in 1953 and 7,463,800 TV receivers turned out during the record year, 1950. The radio production for 1954 was reported as 10,400,530 units compared with 13,368,556 receivers manufactured a year earlier.

Mobilization

The first of four former Liberty ships to be converted by the Navy to ocean radar station ships will be commissioned on February 1 at the Naval Shipyard, Norfolk, Va. The ships will be employed in the continental air defense system. The conversion work primarily involved the installation of bulkheads which created spaces to accommodate communication and electronics equipment, as well as providing additional berthing and messing facilities for the crews. The electronics equipment includes air and surface search radar. Also being installed is a combat information center for evaluating radar information and controlling action of U. S. fighter aircraft against enemy targets, the Navy said.

Technical

The National Bureau of Standards has announced the publication of a new circular which describes its Central Radio Propagation Laboratory's facilities atop Cheyenne Mountain, Colo., and gives sample results of the tropospheric propagation research carried out there. The circular, "Cheyenne Mountain Tropospheric Propagation Experiments," prepared by A. P. Barsis, J. W. Herbstreit and K. O. Hornberg, is available from the Government Printing Office, Washington 25, D. C., for 30 cents per copy. The announcement stated that the mountain site was established for use in studies of tropospheric radio-wave propagation in the VHF and UHF region of the radio spectrum. These facilities include high-power, continuous-wave transmitters on five frequencies, from 92 to 1046 mc. In the circular the new theory of tropospheric propagation, embodying the Booker-Gordon scattering principles as extended by Staras, is related to the measurements. . . . **Men of medicine and industry met recently to discuss how the newest communications medium, color television, can best be used in medical education and also the diagnosis and treatment of disease during a symposium held Jan. 17–19 under the sponsorship of the Armed Forces Institute of Pathology.** The climax of the three day meeting was the performance of an operation which brought pathologists from different cities together for consultation. Four closed circuit television presentations were received at the

(*Continued on page 24A*)

two completely new

SIGNAL GENERATORS

amplifiers, broad band amplifiers and other VHF equipment. Its 1 v output is more than sufficient to drive bridges, slotted lines, transmission lines, antennas, filter networks and other circuits.

Outstanding features in both

Both *-hp-* 608D and 608C have broadest possible modulation capabilities. There is AM modulation to 80%, and flat response 20 cps to 1 mc which provides high quality internal and external pulse modulation. RF leakage is negligible, and sensitivity measurements to 0.1 μv are possible. Internal impedance is 50 ohms constant, and VSWR is a maximum of 1.2.

Both instruments also feature new mechanical design and quality construction throughout. New aluminum castings and cabinets reduce weight. Circuitry is particularly clean and accessible. Dial, condenser and turret drives are ball-bearing. Variable condensers are specially manufactured by *-hp-* and feature electrically welded Invar low temperature steel plates to minimize drift. Sealed transformers are used throughout, and construction is militarized.

Data subject to change without notice. Prices f.o.b. factory

WRITE FOR COMPLETE DATA

HEWLETT-PACKARD COMPANY

3099D Page Mill Road • Palo Alto, California, U.S.A.

SALES AND ENGINEERING REPRESENTATIVES THROUGHOUT THE WORLD

SPECIFICATIONS

-hp- 608D VHF Signal Generator

Frequency Range: 10 to 420 mc, 5 bands.

Calibration Accuracy: ±0.5% full range.

Resettability: Better than ±0.1% after warm-up.

Crystal Calibrator: Frequency check points every 5 mc through range. Headphone jack for audio frequency output.

Frequency Drift: Less than 0.005% over 15 minute interval after warm-up.

Output Level: 0.1 μv to 0.5 v into 50-ohm load. Attenuator dial calibrated in v and dbm. (0 dbm equals 1 mw in 50 ohms.)

Voltage Accuracy: ±1 db full range.

Generator Impedance: 50 ohms, maximum VSWR 1.2.

Modulation Percentage: 0 to 80% indicated by meter.

Envelope Distortion: Less than 2.5% at 30% sine wave modulation.

Internal Modulation: 400 cps ±10% and 1,000 cps ±10%.

External Modulation: 0 to 80%, 20 cps to 100 kc. For RF output above 100 mc, 0 to 30% to 1 mc.

External Pulse Modulation: 10 v peak pulse required. Good pulse shape at 1 μsec.

Residual FM: Less than 1,000 cycles at 30% AM for RF output frequencies above 100 mc. Less than 0.001% below 100 mc.

Leakage: Negligible; permits sensitivity measurements to 0.1 microvolt.

Filament Regulation: Provides highest possible oscillator and amplifier stability for line voltage change.

Power: 115/230 volts ±10%, 50/1,000 cps. Approx. 150 watts.

Size: 13⅜" wide x 16" high x 20½" deep.

Weight: 70 lbs. Shipping weight. approx. 100 lbs.

Price: $1050.00.

-hp- 608C VHF Signal Generator

Same as *-hp-* 608D, except:

Frequency Range: 10 to 480 mc, 5 bands.

Crystal Calibrator: In Model 608D only.

Frequency Drift: Less than ±0.01% over 10 minute interval after warm-up.

Output Level: 0.1 μv to 1.0 v.

Residual FM: Less than 0.0025% at 30% amplitude modulation for RF output frequencies 21 to 480 mc.

Filament Regulation: In Model 608D only.

Price: $950.00.

INSTRUMENTS • COMPLETE COVERAGE

Industrial Engineering Notes

(Continued from page 14A)

Institute from the hospital of the University of Pennsylvania, from studios in Baltimore, and from the National Naval Medical Center at Bethesda, Md. The Television Committee of the Armed Forces Institute of Pathology announced the names of some of the participants in the meetings. Included among the communications experts were Dr. A. N. Goldsmith, Chief Consultant for RCA; Dr. Peter C. Goldmark, Vice-President, Columbia Broadcasting System Laboratories; Edward W. Allen, Chief Engineer of the FCC; Dr. Axel G. Jensen, Director of Television Research of the Bell Telephone Laboratories, and Maj. Gen. G. I. Back, the Army's Chief Signal Officer. . . . **A large reduction in engineering time and costs for selecting proper components to be used in electronic equipment is claimed for a mechanized system for storing and searching engineering data, the Office of Technical Services, Commerce Department, has announced.** Details of this system, entitled the "Electronic Component Information Center (ECIC)," are contained in a research report recently made available to industry by the OTS. This report of research, by Battelle Memorial Institute under an Air Force contract, describes the elements of a machine-sorted punched-card system for recording, searching and tabulating data on an electronic component. Its importance is pointed up by the fact that proper selection of the most reliable and effective components is often the most costly and difficult step in the development of complex electronic systems. Complete details on the new system are available from the Office of Technical Services, Commerce Department, Washington 25, D. C., for $4.25 each and should be ordered by number (PB 111548). . . . **The Atomic Energy Commission . . . released 21 additional patents, including six in the electronics field.** Non-exclusive, royalty-free licenses on the listed patents, as part of its program to make non-secret technological information available for use by industry, will be granted by the commission. Commission-held patents and patent applications released for licensing now total 747. Applicants for licenses should apply to the Chief, Patent Branch, Office of the General Counsel, U. S. Atomic Energy Commission, Washington 25, D. C., identifying the subject matter by patent number and title. The following six patents of interest to the electronics industry were released: High-Voltage Bushing, 2,692,297; Pulse Analyzer, 2,694,146; Electrostatic Amplifier, 2,696,530; Dual Circuit Electrical Safety Device, 2,696,-539; Radio Electric Generator, 2,696,564, and Ion Source, 2,697,788. . . . **The Office of Technical Services, Commerce Department, has listed studies in the field of electronics in its December–January issues of the "Bibliography of Technical Reports."** The following government-sponsored research reports may be purchased from the Photoduplication Section, Library of Congress, Washington 25, D. C. "Basic Methods for the Calibration of

(Continued on page 29A)

(Continued from page 24A)

Sonar Equipment," PB 115485, microfilm, $4; enlargement print, $12.75. "Development of Harmonic Mode Crystals. Final Report," PB 115059, microfilm, $4; photocopy, $11.50. "Diffraction of Pulses by a Circular Cylinder," PB 115215, microfilm, $2.75; photocopy, $6.50. "Dual-Channel Rotary Joint for 3300 mc," PB 115441, microfilm, $1.50; photocopy, $1.50. "Electronic Structure of Solids. II: The Perturbed Periodic Lattice," PB 115261, microfilm, $4; photocopy, $11.50. "IFF Antenna for Mounting on the Wing of a TBM Torpedo Bomber," PB 104816, microfilm, $2; photocopy, $2.75. "Interaction of Electrons and R-F Fields. Technical Report No. 1," PB 115243, microfilm, $2.50; photocopy, $5.25. "Recommended Designations of Radar Indicator Types," PB 110303, microfilm, $1.50; photocopy, $1.50. "Theory of Electromagnetic Corrections to Geometrical Optics," PB 115227, microfilm, $1.50; photocopy, $1.50. "Research Services and Investigations on Subminiature Multielement Diodes and Bistable Elements for Microtronic Circuit," PB 115274, microfilm, $2.50; photocopy, $5.25. "Services, Facilities and Materials Required for Research and Development of Accurate Fixed, Nonwire-Wound Resistors. Final Progress Report," PB 115407, microfilm, $4.75; photocopy, $14. "Studies and Investigations of a 100 Watt CW X-band Klystron," PB 115585, microfilm, $3.25; photocopy, $9. "Research on Electromagnetic Reflections from Surfaces of Complex Shape," PB 115547, microfilm, $2; photocopy, $2.75. "Propagation of Plane Electromagnetic Waves Past a Shoreline," PB 115630, microfilm, $3.25; photocopy, $9. "Reflection and Transmission of Electromagnetic Waves by a Spherical Shell," PB 115629, microfilm, $2; photocopy, $2.75. "Multiple Scattering of Radiation," PB 115643, microfilm, $3.75; photocopy, $10.25. "Mechanical Resonant Scanner," PB 115605, microfilm, $2.25; photocopy, $4. "Microwave Research," PB 115618, microfilm, $2.25; photocopy, $4. "Addition Theorems for Spherical Waves," PB 115650, microfilm, $2.25; photocopy, $4. "Characteristics of Ridge Waveguide. Space Charge Effects in Reflex Klystrons," PB 110058, microfilm, $2; photocopy, $2.75. "Diffraction of Electromagnetic Waves by a Plane Wire Grating, II," PB 115647, microfilm, $2; photocopy, $2.75. "Diffraction of an Arbitrary Pulse by a Wedge," PB 115649, microfilm, $2.25; photocopy, $4. "Linear Ordinary Differential Operators of the Second Order," PB 115648, microfilm, $2.25; photocopy, $4. "Maxwell's Equations in Spherically Symmetric Media," PB 115636, microfilm, $2.25; photocopy, $4. "On the Scattering Effect of a Rough Plane Surface," PB 115646, microfilm, $2; photocopy, $2.75. "Electronic Cursor for AN/APS-15," PB 106688, microfilm, $2; photocopy, $2.75. "Intermodulation Distortion in Mixers," PB 115589, microfilm, $2.50; photocopy, $5.25. "New Ring Counter for Junction Transistors and Vacuum Tubes," PB 115588, microfilm, $2.25; photocopy, $4.

NEWS and NEW PRODUCTS

April 1955

Servo Systems Brochure

Feedback Controls, Inc., 1332 N. Henry St., Alexandria, Va., has available a detailed and illustrated brochure describing their complete line of servos and associated equipment. It is a standardized system of units, adaptable to many problems.

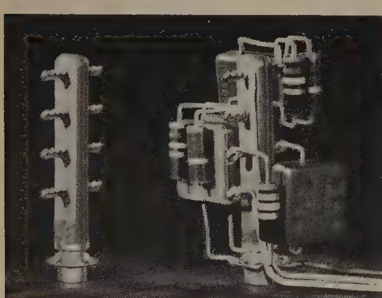
Casting Resin

A two-part casting resin which is easy to use and requires no additional catalyst is announced by **Emerson & Cuming, Inc.,** 869 Washington St., Canton, Mass.

Stycast 2340M has excellent electrical and mechanical properties. Warming the two components to about 125°F facilitates mixing and pouring the material which curves to a tack-free, brown, opaque, resin which is tough, and flexible. Its adhesion to metals, plastics, glass, etc. is also good. Stycast 2340M may be machined and is usable over a temperature range of −100°F to ±400°F without loss of physical or electrical properties.

Component Mount

A new component mounting post called the Tote-m-pole has been developed by **Sangamo Electric Co.,** Springfield, Ill., to improve the "bug resistance" of model and production wiring in government and industrial gear. It provides ideal mounting support for small components such as resistors, capacitors, diodes and transistors at their operating point. Critical leads to grid suppressor resistors, for example, can be reduced to pigtails.



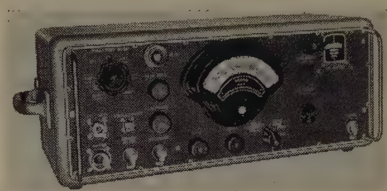
The device assists the engineer to get near optimum component density and point-to-point wiring. Fewer leads, cables and soldered joints are necessary. Users report as much as 5 feet of wire saved by each Tote-m-pole. Ventilation of parts mounted with this wiring aid is excellent. A melamine pole gives it its low tracking, heat-resistant properties. Post illustrated has 5 resistors and 4 capacitors attached.

The Tote-m-pole mounts with a single chassis drill hole. It can be reused many times for model mock-up or component replacement. It is adapted to jig wiring practices whether the jig is of cardboard for design study or a production type.

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

Interference-Field Intensity Meter

The NM-30A radio interference-field intensity meter developed by **Stoddart Aircraft Radio Co., Inc.,** 6644 Santa Monica Blvd., Hollywood 38, Calif., is a precision made equipment for the accurate measurement of field intensities of signals and rf disturbances within the frequency range of 20 to 400 mc.



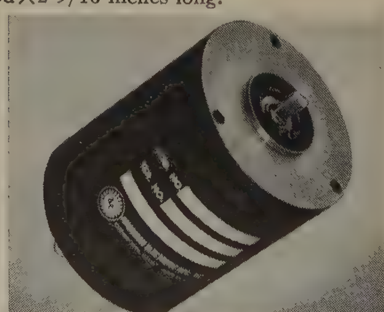
Radio signals or interference, either radiated or conducted, may be measured through the use of accessories which are available for the equipment. Sine wave, pulsed rf, impulsive and random noise may be readily measured. Average, quasi-peak or peak values of complex waveforms can be selected. The NM-30A may also be used as a two-terminal frequency selective voltmeter.

Field intensity surveys, antenna radiation pattern studies and interference location and measurement are but a few of the many uses of the versatile NM-30A.

The NM-30A operates from either 105 to 125 volts or 210 to 250 volts ac, single phase, at any frequency between 50 and 1,000 cps.

Miniature Actuator Motor

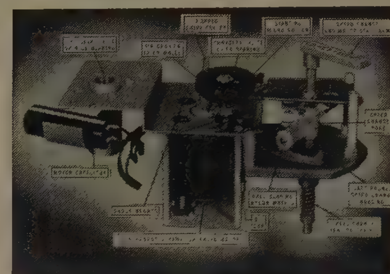
American Electronic Mfg., Inc., Instrument Div., American Electronics, Inc., 9503 W. Jefferson Blvd., Culver City, Calif., is now in production on a small actuator motor measuring 1.705 inches od×2 9/16 inches long.



The motor operates on 400 cps. It is excited with 115 v on the fixed phase and 24 v on the control phase. Torque at stall is 2.9 inch/ounces with a power factor at stall torque of 50 per cent. No load speed is 5,100 rpm. Temperature range: −55°C to 90°C. Weight is 13.7 ounces. Additional data is available from the manufacturer.

Three-Speed Turntable

Gates Radio Co., Quincy, Ill., has a new three-speed turntable for continuous broadcast duty.



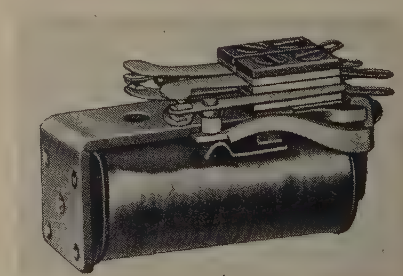
All three speeds, plus motor starting, are controlled by one-flip-type lever.

Speed change mechanism by the use of ball-bearing nylon wheels on a diagonal aluminum casting, running against a cast bronze cam, provides smooth, quiet operation for all three speeds. Increased torque is developed through a synchronous motor that operates the drive arrangement. It is claimed that the timing is exceedingly accurate and slippage practically eliminated. Three diameters on the motor shaft engage with the neoprene idler wheel which in turn drives inside platter rim.

Recession in center of platter with large spindle accommodates 45 RPM records and eliminates the necessity for spindle change for $33\frac{1}{3}$ and 78 recordings. Size of cabinet is $29\frac{1}{2} \times 21\frac{1}{4} \times 21\frac{1}{4}$ inches.

Relay

Available in 1 to 5 amperes contact ratings, and in contact combinations from SPST to 6 PDT, the new relay, announced by the **Advance Electric & Relay Co.,** 2435 N. Naomi St., Burbank, Calif., offers a maximum sensitivity of 15 milliwatts per pole in the dpdt combination. This is an optimum combination, withstanding 10 G's vibration from 10 to 500 cps. When power is increased to 40 milliwatts per pole, vibration resistance rises to 30 G's. Sensitivity and vibration resistance decrease as additional contact combinations are added with the same amount of power.



Friction-creating hinge pins are eliminated, and the use of a beryllium copper armature retaining spring insures positive contact between armature and pivot point at all times.

Cross-bar palladium-type contacts are

(Continued on page 36A)

News-New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 34A)

always properly aligned. A long nylon bobbin, fastened to the frame and core assembly by means of a snap-ring, permits the selection of many types of wire insulation, and allows, in addition, the winding of any type of coil including multiple and matched windings. The unit is insulated with Silicon glass, Kel-F, or Teflon tubing. Movable blades are actuated by ceramic bumpers, with nylon or linen-base bakelite optional.

The SQ withstands the Signal Corps tumbling tests and shock for mechanical damage in excess of 200 G's with operating characteristics unimpaired.

Arbor Listing

Precision Paper Tube Corp., 2035 W. Charleston St., Chicago 47, Ill., has published a new arbor list. It contains specifications on over 2,000 coil forms in all shapes, sizes, id's and od's.

Miniature Relays

Pacific Relays, Inc., 6819 Melrose Ave., Los Angeles 38, Calif., announces the new subminiature "CPL" series of miniature relays. It is designed for application where size, sensitivity and low and high temperature are a major factor. These units are hermetically sealed and are $\frac{3}{4}$ inch$\times\frac{15}{16}$ inch$\times 1\frac{3}{8}$ inches and weigh 1 ounce. It is available to spdt (CPL-1) and in dpdt (CPL-2), contacting ratings to 5 amperes resistive at 28 vdc 115 vac or 3 amperes inductive. Temperature range is 55° to +125°, Vibration—15 G's through 500 cps, Shock—50 G's. Operational life is in excess of 1 million cycles under 1 ampere resistive load. For further information, write to the manufacturer.

(Continued on page 121A)

Membership

The following transfers and admissions were approved to be effective as of February 1, 1955:

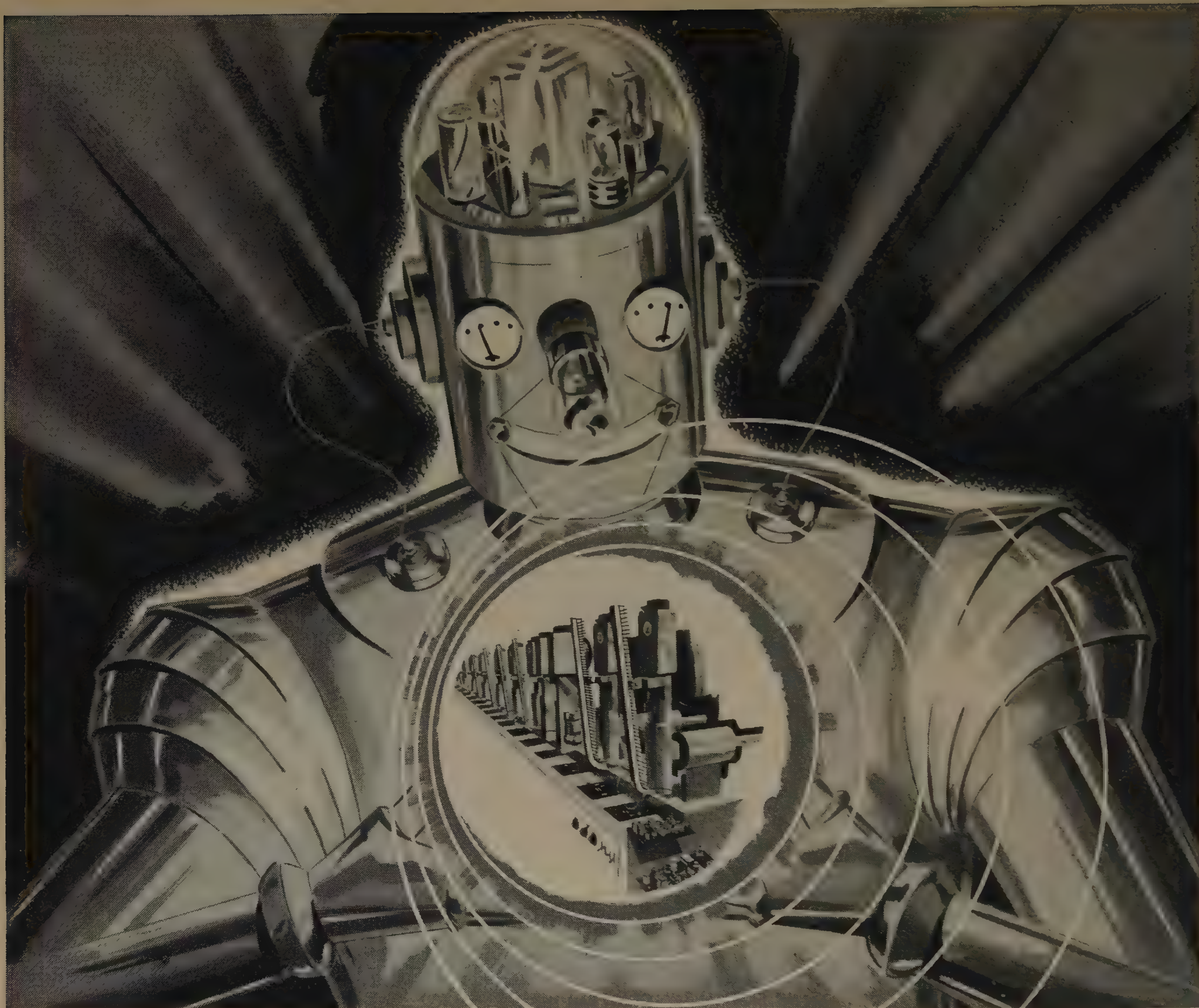
Transfer to Senior Member

Abraham, W. G., Varian Associates, 611 Hansen Way, Palo Alto, Calif.
Arams, F. R., RCA, Bldg. 55-1, Harrison, N. J.
Bell, J. F., 618 Meadow Dr., Glenview, Ill.
Biberman, L. M., 703A, Lexington, China Lake, Calif.
Borders, C. R., 2929 Broadway, New York, N. Y.
Bristol, T. R., RD 1, Ballston Lake, N. Y.
Buggy, R. V., 5934 N. Seventh St., Philadelphia, Pa.
Chelgren, A. E., 576 Fairview Ave., Elmhurst, Ill.
Crothers, H. H., c/o Electrical Engineering Dept., University of Illinois, Urbana, Ill.
Eannarino, J. M., 610 Highland Ave., Rome, N. Y.
Galagan, S., 136 Fessenden St., Newtonville, Mass.
Goldstone, L. O., 226-17 Manor Rd., Queens Village, N. Y.
Hawkins, W. G., 4506 Atwood, Fort Wayne, Ind.
Hogan, D. L., 12512 Epping Ct., Silver Spring, Md.
Hoglund, R. H., 1825 E. Lynn St., Seattle, Wash.
Hutton, W. I., 35 Gilmore Blvd. North, Wappingers Falls, N. Y.
Kahrilas, P. J., 9345 Loyola Blvd., Los Angeles, Calif.
Kirby, T. H., Cow Hill Rd., Mystic, Conn.
Klawsnik, F., 142 Norwood Ave., Brooklyn, N. Y.
Lapin, S. P., 1214 W. Jarvis Ave., Chicago, Ill.
Manning, L. A., 649 Alvarado Row, Stanford, Calif.
Marion, T. M., 1699 Carling Ave., Ottawa, Ont., Canada
Mattingly, R. L., Bell Telephone Labs., Whippany, N. J.
Meek, T. J., Jr., 1001 McLeod Bldg., Edmonton, Alta., Canada
Meyer, A., 4280 Orchard La., Cincinnati, Ohio
Mooney, V. J., 104 Carnation Ave., Florak Pk., L. I., N. Y.
Pankove, J. I., RCA Labs., Princeton, N. J.
Pelc, T., 2775 Delta Ave., Long Beach, Calif.
Pihl, G. E., 46 Elm, Abington, Mass.
Powers, A. B., Box 2117, Riverside, Calif.
St. John, E. E., 4931 W. 122 St., Hawthorne, Calif.
Serota, R. M., 1861 Burnette Ave., E. Cleveland, Ohio
Shankweiler, R. G., Plainsboro Rd., Cranbury, N. J.
Smith, H. M., Electron Tube Lab., Hughes Aircraft Co., Culver City, Calif.
Smith, M. C., 812 Inverness Dr., Pasadena, Calif.
Ulmer, H. W., 302 N. Clementine St., Oceanside, Calif.
Whitcraft, W. A., Jr., 60 Division St., Malden, Mass.
Woodrow, G. V., Jr., 1530 Providence Rd., RD 6, Towson, Md.
Wroblewski, T., 7 Belgian Rd., Danvers, Mass.

Admission to Senior Member

Alfven, H., Sweden, Bergsvagen 33, Stockholm 70, Kungl. Tekniska Hogskolan, Sweden
Alma, G., c/o Bibliotheekcentrale, N. V. Philips' Gloeilampenfabrieken Eindhoven, Holland
Arlowe, H. H., 1707 N. 50 St., Seattle, Wash.
Azgapetian, V., 40 Shelter La., Roslyn Hghts., L. I., N. Y.
Bennett, B. J., Stanford Research Inst., Stanford, Calif.
Doehler, O., 21 Bld. de L'Ermitage, Montmorency S.et.O, France
Edgerton, H. E., 205 School St., Belmont, Mass.
England, W. B., 46 Lynwood Dr., Rochester, N. Y.
Fleming-Williams, B. C., 18 Grove Ter., Highgate Rd., London N.W. 5, England

(Continued on page 45A)



Everybody *talks* about AUTOMATION...
Admiral® has it!

Automation, at Admiral, is an established fact . . . fully proved-in-practice on a wholly automatic assembly line which for many months has been producing electronic assemblies at rates up to 5,000 per day.

The importance of automation to the production of military electronic equipment cannot be over-stated. For one thing, automation substantially reduces unit costs . . . makes expendable items less expensive. Automation also guards against error and helps to maintain unwavering quality standards.

The automation equipment now in use was designed, developed and produced by Admiral's own engineering staff. Facilities are available for the production of electronic or electromechanical units in virtually any quantity, large or small. Address inquiries to:

Admiral Corporation

Government Laboratories Division, Chicago 47, Illinois

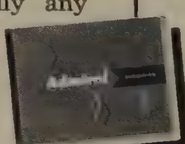
NOTE: COLOR SOUND FILM on Automation available for showing to technical or business groups. Film runs 9 minutes. Address requests to Public Relations Director, Admiral Corporation, Chicago 47, Ill.

*Look to **Admiral** for*

- RESEARCH
- DEVELOPMENT
- PRODUCTION

in the fields of:

COMMUNICATIONS, UHF and VHF, air-borne and ground.
MILITARY TELEVISION, receiving and transmitting, air-borne and ground.
RADAR, air-borne, ship and ground.
RADIAC • MISSILE GUIDANCE
TELEMETERING
CODERS and DECODERS
DISTANCE MEASURING
TEST EQUIPMENT



Send for Brochure . . . complete digest of Admiral's experience, equipment and facilities.

ENGINEERS! The wide scope of work in progress at Admiral creates challenging opportunities in the field of your choice. Write to Director of Engineering, Admiral Corporation, Chicago 47, Ill.

Membership

(Continued from page 41A)

Foster, H. G., 28 Essex St., Strand, London, W.C 2, England
Gamache, L. J., Motorola, Inc., 4545 W. Augusta Blvd., Chicago, Ill.
Geier, L. W., 51 Felch Rd., Natick, Mass.
Haberstroh, A., 9 Black Horse La., Cohasset, Mass.
Hillier, J., RCA Labs., Princeton, N. J.
Kelly, J. H., 161 W. 16 St., New York, N. Y.
Keyser, J. H., Jr., 4725 Hampton Rd., La Canada, Calif.
Lazar, E. F., Sperry Gyroscope Co., Great Neck, L. I., N. Y.
Masson, F. Y., 340 Cleveland St., Orange, N. J.
McCord, W. O., Jr., 3405—51 Loop, Sandia Base, Albuquerque, N. Mex.
Newell, L. T., 6615 Nall Dr., Mission, Kan.
Newton, L. W., 5 Market St., Nashua, N. H.
Read, A. H., British Embassy, 3100 Massachusetts Ave., N.W., Washington, D. C.
Ryerson, C. M., 626 Wayne Ave., Haddonfield, N. J.
Sinish, R. D., 2723 Indiana Ave., Fort Wayne, Ind.
Souder, C. W., 2 Sycamore Ave., Glen Cover, L. I., N. Y.
Welsh, J. P., 544 Lisbon Ave., Buffalo, N. Y.
Zinn, W. H., Box 299, Lemont, Ill.

Transfer to Member

Alrich, J. C., 1268 Sunny Oaks Circle, Altadena, Calif.
Arnold, J. B., 115 Hillwood Ave., Falls Church, Va.
Bauer, P. S., Jr., 702 Mattison Ave., Asbury Pk., N. J.
Benner, B., 930 Huron River Dr., Belleville, Mich.
Birch, J. S., 504 Lee St., Seattle, Wash.
Britton, C. C., Dept. Electrical Engineering, Colorado A & M College, Fort Collins, Col.
Brown, G. L., 2100 John St., Ponca City, Okla.
Campbell, R., 6352—49 St., San Diego, Calif.
Clark, R. G., 1732 Howell, Richland, Wash.
Cooper, R. E., Jr., 28 E. Bruce Ave., Dayton, Ohio
Ehrlich, N., 114 Franklin St., Apt. 7E-1, Morristown, N. J.
Eiden, G. E., Farnsworth Electronics Co., Fort Wayne, Ind.
Emmons, A. W., 1308 S. Ridgewood Ave., Daytona Beach, Fla.
Fredman, N. E., 7871 Clearfield Ave., Van Nuys, Calif.
Glaser, E. M., 1315 St. Paul St., Baltimore, Md.
Graham, N. L., 1811 Fifth Ave., S.E., Cedar Rapids, Iowa
Haber, F., 873 Fairfax Rd., Drexel Hill, Pa.
Henry, J. L., c/o Sea Lawn Apts., Cocoa Beach, Fla.
Hymowitz, E. W., Electronics Test (Radar), NATC—Patuxent River, Md.
Jones, H., Burnbank, Goosewell Hill, Eggbuckland, Plymouth, Devon, England
Kieshauer, F. W., Apt. C-205, 1420 Pacific Ave., Brackenridge, Pa.
Krause, C. A., 9332 Glasgow Pl., Los Angeles, Calif.
Levy, L. G., 53 B Pkway Apts., Haddonfield, N. J.
Markham, I. F., Box 5, Jewell, N. Y.
Matte, G. W., CASEE—DND (Army), Ottawa, Ontario, Canada
Mitchell, J. L., 1821 W. 14½ St., Houston, Tex.
Montllor, J. A., 1 Cataract Hollow Rd., Scotch Plains, N. J.
Morgen, M., 2144—64 St., Brooklyn, N. Y.
Nelson, J. L., 767 Shoshone Ave., Akron, Ohio
Norris, P. C., 1337 Forest Glen Dr., Cuyahoga Falls, Ohio
Owens, D. L., Box 617, Akron, Ohio
Potter, R. R., Box 16, Dahlgren, Va.

(Continued on page 48A)

Membership

(Continued from page 45A)

Robison, W. C., 309 Ferguson Hall, University of Nebraska, Lincoln, Neb.
Rusnak, M., 5467 Ingleside Ave., Chicago, Ill.
Ryan, R. D., 83 Cottenham Ave., Kingsford, Sydney, N.S.W., Australia
Sabo, J. N., 69 Billington Pl., Fort Wayne, Ind.
Schmidt, R. W., 8405 S.W. Ninth Ave., Portland, Ore.
Sleman, G. R., Nova Scotia Tech. College, Halifax, Nova Scotia, Canada
Spear, W. G., 1519 McPherson, Richland, Wash.
Starzec, F. J., 6837 W. Imlay St., Chicago, Ill.
Thompson, D. G., 4620 Knox Rd., Apt. 4, College Pk., Md.
Tuma, W. S., 4407 Grantwood Dr., Parma, Ohio
Turnage, H. C., 1107 Country Club Rd., Warwick, Va.
Weber, S. E., 205 W. Second St., Arcanum, Ohio
Weisman, I., 2811 Exterior St., Bronx, N. Y.
Wilkinson, J. H., 1438 Elkgrove Circle, Venice, Calif.
Wirth, C. H., 78 N. Spring Garden Ave., Nutley, N. J.
Wood, C. E., 6650 S. Cicero Ave., Chicago, Ill.
Yeh, L. P., Elec. Dept., Colorado A & M College, Ft. Collins, Col.

Admission to Member

Alexakis, N. G., 320 S. Cummings St., Los Angeles, Calif.
Alley, J. W., American Embassy, Colombo, Ceylon, c/o U. S. Dept. of State Mailroom, Washington, D. C.
Bass, J. W., 1830 El Dorado St., W. Covina, Calif.
Berman, B., 5313 Dawes Ave., Culver City, Calif.
Brown, L. E., 5573 W. Jackson Blvd., Chicago, Ill.
Brunton, H. W., Apt. 116, 415 Lakeshore Rd., Toronto, Ont., Canada
Chun, B., 105–30—66 Ave., Forest Hills, L. I., N. Y.
Comer, J. L., 68-35 Burns St., Forest Hills, L. I., N. Y.
Custer, H. M., 632 S. Locust St., Elizabethtown, Pa.
Cutlip, S. B., 2230 Birchwood Ave., Wilmette, Ill.
David, E., 5185 Borden Ave., Montreal, Que., Canada
De Haas, J., Cia. Shell De Venezuela, Apt. 19, Maracaibo, Venezuela
Ditrick, N. H., 10 Chestnut St., E Orange, N. J.
Dube, J. J., 11845 Guertin St., Montreal, Que., Canada
Duchesneau, B. E., 1821 S. Pinecrest, Wichita, Kan.
Edens, R. L., 313½ N. Prairie St., Dallas, Tex.
Eldon, C. A., 3728 Carlson Cir., Palo Alto, Calif.
El-Sabbagh, H. H., 705 W. California, Urbana, Ill.
Evans, W. L., Convair, Grants La., Ft. Worth, Tex.
Ferguson, P. M., 1703 N. College, Tulsa, Okla.
Fichter, W. C., Jr., May St., Bath, N. Y.
Freen, P., Benco Television Associates Ltd., 130 Simcoe, Toronto, Ont., Canada
Gainey, L. L., Hoffman Ave. & Marlton Pike, Merchantville, N. J.
Gore, L. D., 7 W. Campbell Ave., W. Long Branch, N. J.
Gudmundsen, R. A., Hughes Aircraft Co., 5315 W. 102 St., Los Angeles, Calif.
Hawkins, E. S., 4309 S.E. Anthony Wayne Dr., Ft. Wayne, Ind.
Hierlihy, O. G., Newfoundland Broadcasting Co., Prince of Wales St., St. Johns, Newfoundland, Canada
Hirschl, L., 827 Pearl St., Santa Monica, Calif.
Hobbs, C. A., Jr., 122 E. Stiles Ave., Collingswood, N. J.
Holt, C. A., Box 565, Blacksburg, Va.
House, A. N., 26 Cornwall Ave., St. John's, Newfoundland, Canada

(Continued on page 52A)

Membership

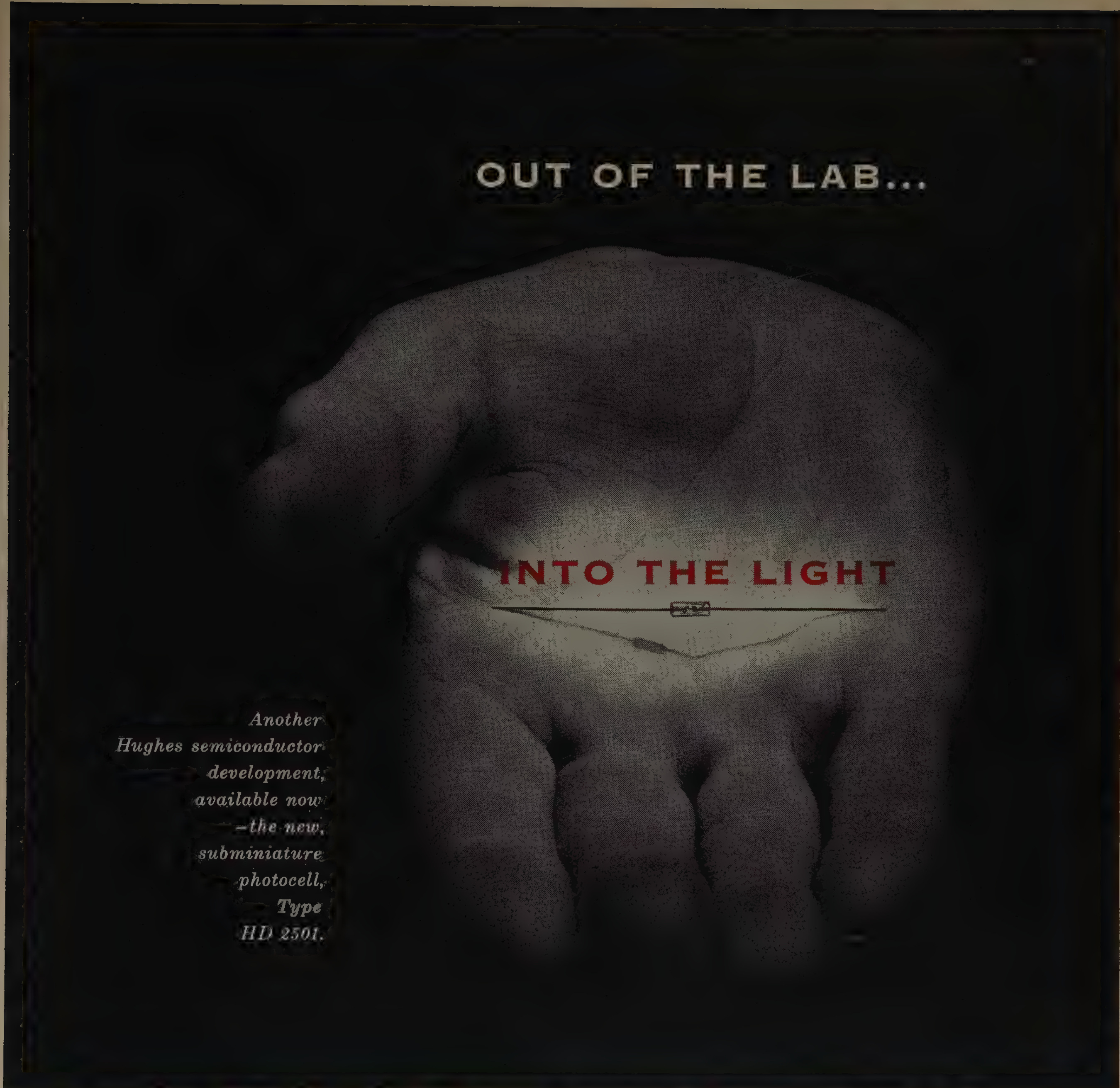
(Continued from page 48A)

Howe, D. H., 502 Wherry Dr., White Sands Proving Ground, N. Mex.
Ibbett, D. B. C., 115 Vachon St., Eastview, Ont., Canada
Kehm, C. H., 1947 N. Kildare Ave., Chicago, Ill.
Khan, A. R., 44/3/1 Vithalbhai Patel Rd., Karachi, Pakistan
Kiss, F. V., c/o Northern Transportation Co., Ltd., 10040—105 St., Edmonton, Alta., Canada
Kompass, E. J., 270 Glen Ave., Dumont, N. J.
Koster, J. A., 59 Delisle Ave., Toronto, Ont., Canada
Krystek, M. E., 1835 N.W. 16 St., Oklahoma City, Okla.
Latimer, D. T., Jr., 47 E. Rennell Ave., Lexington Pk., Md.
Lawton, H. D., 605 Glenview Ave., S.W., Glen Burnie, Md.
Morton, W. A., Jr., Cedar Ave., Trailer Pk., New Windsor, N. Y.
Mueller, R. P., 3337 Tech. Training Sqdn., Scott Air Force Base, Ill.
Ochs, S. A., RCA Labs., Princeton, N. J.
Papian, W. N., Rm. B-170, MIT Lincoln Lab., Lexington, Mass.
Papouschek, F., 156 Monterrey, Lakeside, Point Claire, Que., Canada
Pittman, R. R., 6534 Clawson, Houston, Tex.
Primpas, L. V., Sylvania Electric Products, Inc., 70 Forsyth St., Boston, Mass.
Putman, R. E., 420 E. Corey Rd., Syracuse, N. Y.
Rodgers, J. P., Dept. of Transport, 10138—100 A St., Edmonton, Alta., Canada
Rohde, L., 7 Tassiloplatz, Munchen, Germany
Ross, C. J., 1290 E. 19 St., Brooklyn, N. Y.
Sacker, J. E., 10918—88 Ave., Edmonton, Alta., Canada
Seed, R. G., 258 East St., Lexington, Mass.
Shawl, W. C., Hq. 26 Air Div. (Def.) Roslyn, L. I., N. Y.
Stanley, G. M., Box 101, College, Alaska
Stites, F. H., Bennett Rd., Wayland, Mass.
Urling, H. R., 17 Quebec Dr., Huntington, Sta., L. I., N. Y.
Wachendorf, F. A., 19 Preston Beech Rd., Marblehead, Mass.
Walker, B. G., 130 Pine Tree Dr., N. Syracuse, N. Y.
White, J., 5223 W. 92 St., Oak Lawn, Ill.

The following elections to the Associate grade were approved to be effective as of February 1, 1955:

Adams, R. N., Box 820, Melbourne, Fla.
Alexander, M. T., 817 Duke, Greensboro, N. C.
Amdahl, L. D., 2929 Broadway, New York 25, N. Y.
Anderson, E. C., Box 262, 25 Enfield Rd., Colonia, N. J.
Appleton, E. R., 4324 W. Florissant, St. Louis, Mo.
Ault, J. C., 5 Marblehead Dr., Brentwood 17, Mo.
Ball, M., 104 Garden St., Sayre, Pa.
Barber, F. A., 226 Hibiscus Ct., Orlando, Fla.
Barsamian, A. S., 16579 Lilac Ave., Detroit 21, Mich.
Becker, H. D., 45 Heath St., Buffalo, N. Y.
Belitz, H. G., G. H. Leland, Inc., 123 Webster St., Dayton 2, Ohio
Benjamin, H. L., 467 Lesher Dr., Dayton 9, Ohio
Bergen, A. R., 49 Hazelton Rd., Yonkers, N. Y.
Bergen, S., Commercial Radio Equipment Co., 1319 F St., N.W., Washington, D. C.
Berwin, T. W., 5708 Bianca, Encino, Calif.
Bichara, M. R. E., Transvaal Chamber of Mines, Research Laboratories, Box 809, Johannesburg, S. Africa
Bickley, E. B., 13000 Athens Ave., Cleveland 7, Ohio
Bland, S. B., 17638 Lemay Pl., Van Nuys, Calif.

(Continued on page 58A)



SUBMINIATURE—smallest over-all volume of any photoelectric detector (approx. 1/1000 cu. in.).

FUSION-SEALED—only subminiature photocell with true glass-to-metal seal.

FAST—response at 20 kc down less than 5 per cent.

VERSATILE—non-directional sensitivity (360°) and photovoltaic properties lend unusual flexibility in equipment design.

RUGGED—welded whisker construction withstands severe shock, vibration, and acceleration.

RELIABLE—packaged in the famous Hughes one-piece glass envelope, impervious to moisture and external contamination. A 100% testing ensures uniformity of characteristics.

Hughes Type HD 2501 germanium point-contact photocell can be used as a light detector in card readers, binary encoding and decoding wheels, motion picture sound—and for near infrared applications. Because of this infrared response, tungsten light sources can be operated at voltages below normal and their effective life increased accordingly.

For other diode applications in high and low temperature ranges, be sure to check the growing family of Hughes semiconductors. Scores of types of germanium point-contact and silicon junction diodes are available in RETMA, JAN, and Special listings.

HUGHES SEMICONDUCTOR SALES DEPARTMENT

Aircraft Company, Culver City, Calif.

New York Syracuse
Philadelphia Chicago

Photocell dimensions, glass envelope
Length: 0.263-inch, maximum
Diameter: 0.086-inch, maximum

TYPE HD 2501 PHOTOCELL—SOME CHARACTERISTICS AT 25° C.

Dynamic Breakdown Voltage: 175 Volts, minimum.
Maximum Dark Current: 20 μA at 50 Volts.
Minimum Sensitivity: 1mA/L at 50 Volts and 25 ML.
Dynamic Resistance: 1 megohm at 50 Volts and 25 ML.

Membership

(Continued from page 52A)

Bowker, M. W., Bell Telephone Laboratories, Murray Hill, N. J.
Brendecke, W. H., Jr., 3028 N. 47 Pl., Phoenix, Ariz.
Bryla, L., 3242 S. 49 Ave., Cicero 50, Ill.
Buckley, A. E., Jr., 368 Belmont St., Fall River, Mass.
Bull, T. R., 120 Oriole Pkwy., Apt. 401, Toronto 7, Ont., Canada
Busch, K. J., Bell Telephone Laboratories, Inc., Murray Hill, N. J.
Caldwell, A., 11024—100 Ave., Edmonton, Alta., Canada
Carbine, I. L., Box 548, State College, N. Mex.
Clarke, A. F., Jr., 84 E. Bradford Ave., Cedar Grove, N. J.
Comeau, C. P., 8429 Forrest Ave., Philadelphia 19, Pa.
Common, C. A., 921 E. Donmoyer Ave., South Bend 14, Ind.
Conway, P. W., 855 Keystone Cir., Northbrook, Ill.
Cooke, E. R., 145 N. 72 St., Milwaukee, Wis.
Cooper, R. S., Air Force Armament Center, ACVO, Eglin AFB, Fla.
Coria, R. F., 1143 N. Harvard, Tulsa, Okla.
Crowe, E. W., 41 N. Dade Ave., Ferguson, Mo.
Dagostino, V. L., Main St., Stirling, N. J.
Darling, R. E., 513 Mulberry St., Hammond, Ind.
Davies, W. R., J-4 Meadow Styertowne, Clifton, N. J.
Davis, O. R., 403 Tustin Ave., Newport Beach, Calif.
Dettling, A. K., Moores Mills, R.F.D., Pleasant Valley, N. Y.
Dimmick, J. V., 952 Janet La., Lafayette, Calif.
Donelson, L. E., 15465 Gilchrist, Detroit 27, Mich.
Dumey, A. I., 29 Barberry La., Roslyn Heights, L. I., N. Y.
Edgar, G. M., 10312—121 St., Edmonton, Alta., Canada
Edgerton, J. F., The North Country Stations, Box 662, St. Johnsbury, Vt.
Edwards, H. M., 683 Palisade Ave., Yonkers, N. Y.
Ehni, F. P., 413 Dewey La., Alamogordo, N. Mex.
Eisenberg, H., Naval Ordnance Laboratory, White Oak, Silver Spring, Md.
Enander, B. N., RCA Laboratories, Princeton, N. J.
Falk, B., 200 Park Blvd., Crystal Lake, Ill.
Feland, R. F., Jr., 717 N. Lake Ave., Pasadena, Calif.
Ferguson, J. W., 545 Wilson Dr., Midwest City, Okla.
Fiorentino, G., Box 248, New Canaan, Conn.
Fish, K. A., Brown St., Baldwinsville, N. Y.
Fisher, R. M., 565 E. Main St., Moorestown, N. J.
Fockens, P., 5150 W. LeMoyne Ave., Chicago 51, Ill.
Frey, W. A., 410 E. Key Blvd., Midwest City, Okla.
Fuchs, H. B., 150-59—87 Ave., Jamaica, L. I., N. Y.
Fulton, D. A., 6 Summer St., Watertown, Mass.
Garrett, W. A., 324 E. 11 St., Kansas City 6, Mo.
Gerig, J. S., Melpar, Inc., 3000 Arlington Blvd., Falls Church, Va.
Goldstone, G. H., 1926 National Bank Bldg., Detroit, Mich.
Gortley, C., 963 Williams Dr., Alexandria, Va.
Gosch, V. E., 758 Edgbrook La., San Antonio, Tex.
Gottmer, G. W., 3508 S. Maplewood Ave., Chicago, Ill.
Graham, J. D., Electrical Engineering Department, Kansas State College, Manhattan, Kans.
Granger, B. W., 111 Verbena Dr., Palo Alto, Calif.
Gunning, M. E., R.F.D. 1, Medway, Ohio
Guy, R. D., 10035—91 Ave., Edmonton, Alta., Canada
Haulbosky, W. B., Box 199, 3337th Tech. Ing. Sq., Scott AFB, Belleville, Ill.

(Continued on page 60A)


6AX4 GT
TUNG-SOL
MADE IN U. S. A.
6U8
5687
6AU4 GT
5881
6550

Membership

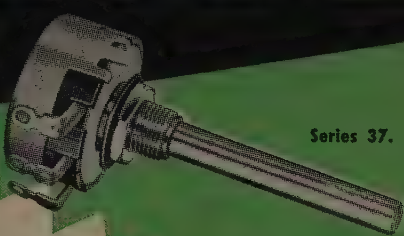
(Continued from page 58A)

Healy, B. H., 41 Pine St., Bedford, Mass.
Heller, P. N., 17 Chauncy St., Cambridge 38, Mass.
Hilker, H. V., Jr., 207 B Groves, China Lake, Calif.
Hill, M. E., Mayflower Apts. 1014, Virginia Beach, Va.
Hines, R. L., 3709 Turner, Fort Worth 7, Tex.
Holliday, T. B., 248 Arlington Ave., Elmhurst, Ill.
Howard, C. T., Raydist Navigation Corp., 2514 W. Pembroke Ave., Hampton, Va.
Howson, J. C., IBM, 590 Madison Ave., New York 22, N. Y.
Huget, W. J., 11638—76 Ave., Edmonton, Alta., Canada
Hughes, E. L., 542 W. James, Apt. 6, Lancaster, Pa.
Humphrey, C. D., 88 Treat Rd., Glastonbury, Conn.
Huntoon, V. J., C-E Co., 3800 N. Milwaukee Ave., Chicago 41, Ill.
Huska, J., 230 Gray Plaza, Scott AFB, Ill.
Hutton, D. B., 915 S. 17 St., Arlington, Va.
Jackson, D. A., 1955A Pine Ave., Long Beach, Calif.
Jadisdha, S., Box 535, 3337 Tech Training Sq., Scott AFB, Ill.
James, R. L., 1119 Grand St., Redwood City, Calif.
Janusz, J. S., 16 W. 37 St., Kansas City, Mo.
Kahn, M. H., Central Eng. & Stores Estab., Karachi Airport, Pakistan
Kaiser, H. F., 2406—34 St., S.E., Washington 20, D. C.
Kazuk, W. F., Pleasant View Dr., Paterson 2, N. J.
Keller, C. C., 980 Memorial Dr., Cambridge 38, Mass.
Kelly, L. J., 8012 Davanagh Rd., Baltimore, Md.
Keltonic, F. J., 111 Huntington St., New London, Conn.
Kidwell, R. P., c/o Billeting Office, White Sands Proving Ground, N. Mex.
Kinsley, R. B., 902 Burrstone Rd., Utica 4, N. Y.
Kondracki, J. J., 2849 H Adams St., Wilmington, N. C.
Konig, H. F., General Electric Co., French Rd., Utica, N. Y.
Koszyn, A. I., 184 E. Mt. Eden Ave., New York 57, N. Y.
Kovacik, F. C., 1925 Euclid Ave., Berwyn, Ill.
Kozak, A. S., 829 Emerson St., N.W., Washington 11, D. C.
Ladd, E. L., c/o United Aircraft Products, Inc., 1116 Bolander Ave., Dayton, Ohio
La Forte, J. T., 160 Crawford St., Rochester 20, N. Y.
Lamb, R. W. H., Radio Station CFCM, Calgary, Alta., Canada
Laugesen, T. C., 48 N. Nelson Cir., Milltown, N. J.
Leach, G. S., 7320 Austin St., Forest Hills 75, L. I., N. Y.
Leitch, J. G., 13024—123 A Ave., Edmonton, Alta., Canada
Leland, H. E., 123 Webster St., c/o G. H. Leland, Inc., Dayton 2, Ohio
Levesque, J. J., R.F.D. 2, Marcoutah, Ill.
Levin, H. L., 415—19 Ave., Paterson 4, N. J.
Lewin, N. L., 7109 S. Bennett, Chicago, Ill.
Lewis, D. E., 288 S. Findlay St., Dayton 3, Ohio
Liang, W. W. L., Electrical Engineering Department, Manhattan College, New York, N. Y.
Lieberman, G., 2106 Reedie Dr., Silver Spring, Md.
Lincoln, C. F., Jr., 3935 Rochelle Dr., Dallas 20, Tex.
Lobb, R. H. M., 438 Federal Bldg. Victoria, B. C., Canada
Loken, R. D., RCA, Front & Cooper Sts., Camden 2, N. J.
Lorenz, E. J., 10 Wasson Dr., Poughkeepsie, N. Y.
Louis, S., M. Kidony 10/127, Haxfira, Moshava Germanit, Jerusalem, Israel
Lowenschuss, O., 67-01—210 St., Bayside, L. I., N. Y.

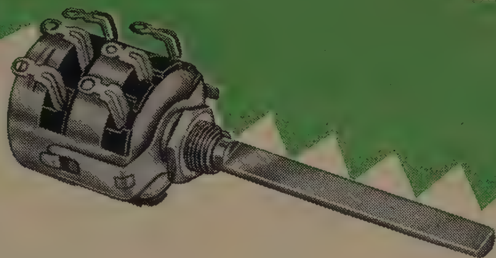
(Continued on page 64A)

STAND PAT WITH CLAROSTAT

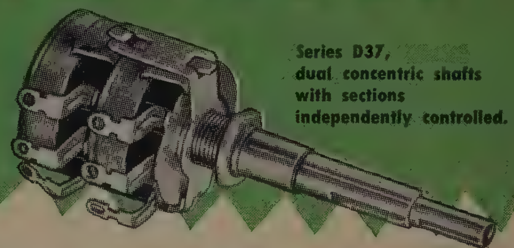
Composition-Element CONTROLS



Series 37.



Series D37, dual with single shaft.



Series D37, dual concentric shafts with sections independently controlled.

It's better, quicker, cheaper, to specify CLAROSTAT for those carbon control requirements, because:

For **usual needs**, there's an adequate choice of standard Clarostat types such as:

SERIES 37: 1-1/8″ d. 0.5 watt. Linear or tapers. One to three taps. Available with switch. Choice of shafts. Singles or duals. 500 ohm to 5 megohms. Approved for Type RV3, characteristic U, MIL-R-94 specification.

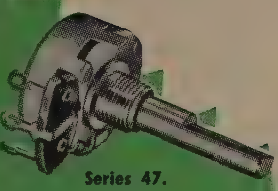
SERIES 47: 15/16″ d. 0.5 watt. Linear or tapers. One tap, choice of three positions. Available with switch. Choice of shafts. Singles or duals. 500 ohms to 5 megohms.

SERIES 48: For miniaturization. 5/8″ d. 0.2 watt. 500 ohms to 5 megohms, linear; or 2,500 ohms to 2.5 megohms, tapers. Singles or duals. Available with switch.

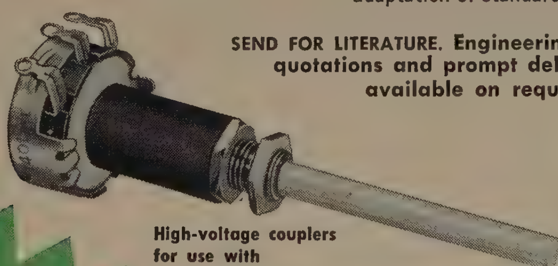
SERIES 51: For high-voltage high-resistance electronic circuitry. 1-17/32″ d. phenolic case. 1 watt. 5,000 ohms to 50 megohms. 10,000 V.D.C. breakdown test between terminals and mounting bushing. Maximum operating voltage, 4,000. Tapers available.

And for **unusual needs**, Clarostat can design and put into production those special types—quickly, satisfactorily, economically — often based on ingenious adaptation of standard features and available tooling.

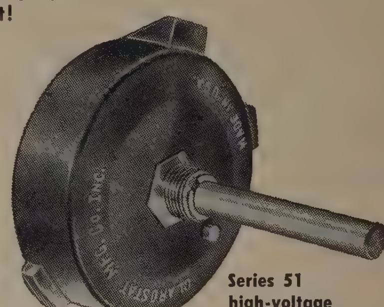
SEND FOR LITERATURE. Engineering collaboration, quotations and prompt delivery cycles, available on request!



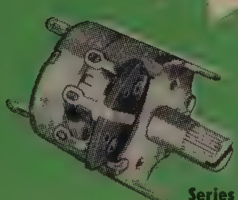
Series 47.



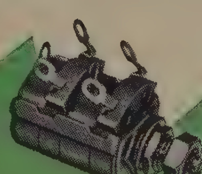
High-voltage couplers for use with elevated potentials.



Series 51 high-voltage high-resistance control.



Series 47S, with switch, and twist-tab mounted.



Series D48 dual control for miniaturization requirements.

CLAROSTAT ®

Controls and Resistors

CLAROSTAT MFG. CO. INC., DOVER, NEW HAMPSHIRE

In Canada: Canadian Marconi Co., Ltd., Toronto 17, Ont. Manufactured under license in Great Britain by A. B. Metal Products Ltd., 17 Stratton St., London W. 1, Concessionaires for British Commonwealth except Canada.

Membership

(*Continued from page 60A*)

Mackay, J. B., Box 41, Highland, N. Y.
Madeson, A. H., 96 Maple Ave., Patchogue, L. I., N. Y.
Maler, P. M., c/o Rocke International Corp., 13 E. 40 St., New York 12, N. Y.
Markesjo, G. A., Hokmossevagen 27, Hagersten, Sweden
Martin, C. E., 3130 Jackson St., Hapeville, Ga.
Martin, L. H., 28 Valley Rd., Concord, Mass.
Martinelli, A. A., 1414 Chelsea St., Winston-Salem, N. C.
Mason, R. K., 1 Duffy Ct., Binghamton, N. Y.
Matovich, M. J., Stanford Research Institute, Stanford, Calif.
Maxey, G. S., Box 3554, R.F.D. 1, Redding, Calif.
Mayer, J. H., 570 Paul St., Hillside 5, N. J.
McCann, R. W., 211 E. Third St., Corning, N. Y.
McMath, D. C., Jr., 1436 S. Madison St., Huntsville, Ala
Messina, A. S., 779 E. Second St., Brooklyn, N. Y.
Mickleburgh, W. C., 9393 Technical Service Unit, Detachment 2, Box 306, White Sands Proving Ground, N. Mex.
Miraglia, J. F., 1615 Ventura Dr., Tempe, Ariz.
Montgomery, E. B., 1944 Davison, Richland, Wash.
Murray, R., Jr., 1874 Davis St., Elmira, N. Y.
Mushiake, Y., c/o Antenna Laboratory, Electrical Engineering Bldg., Ohio State University, Columbus, Ohio
Mutchek, J. H., R.F.D. 5, Deppe La., East St. Louis, Ill.
Newhouse, V. L., Box 179, Marion, Iowa
Nolan, J. J., 314 W. Sparks St., Philadelphia 20, Pa.
Northrup, R. M., Box 52, Emporium, Pa.
O'Hara, F. J., 5 Scott Rd., Belmont 78, Mass.
Olsen, J. C., 1628 Pleasantdale, Cleveland 9, Ohio
O'Neil, J. F., Jr., 121 Hesper St., Saugus, Mass.
Pallange, E. P., Box 444, Quaker Hill, Conn.
Palmieri, C. A., 35-16—33 St., Long Island City, L. I., N. Y.
Parkes, R., 11324—73 Ave., Edmonton, Alta., Canada
Pascal, J., 13919—102 Ave., Edmonton, Alta., Canada
Patton, R. C., 1106 Chicago, Valparaiso, Ind.
Pelles, Y., c/o J. Gilat 3 Zerubabel, Haifa, Israel
Perkins, J. F., Jr., 48 Collimore Rd., E. Hartford, Conn.
Phelan, J. L., 11310—110 A Ave., Edmonton, Alta., Canada
Phillips, W. F., 3337 Tech. Ing. Sq., Box 38, Scott AFB, Ill.
Pitts, E. H., 515 W. Clinton St., Huntsville, Ala.
Poehler, H., 101 Bedford St., Lexington, Mass.
Ponte, A. G., 205 Fourth Ave., White Sands Proving Ground, N. Mex.
Popovich, R. G., 1019 Georges Rd., New Brunswick, N. J.
Powley, R. K., 11167—62 Ave., Edmonton, Alta., Canada
Prier, H. W., 3030 S. Polk, Dallas, Tex.
Pyle, C. A., Dyn. SYS. Br., EMLD, White Sands Proving Ground, N. Mex.
Rachlin, M., 1216 Unruh Ave., Philadelphia, Pa.
Ramant, S., Artillery Static Workshop, Deolali, Nasik Dt., Bombay State, India
Rao, V. K., c/o V. Ramamurti 5/56 Venkatrayudu, Pulla, Eluru Taluk Andhra, India
Raymond, J. E., 8912—116 St., Edmonton, Alta., Canada
Reasor, W. J., 84 Peachtree St., N.W., Atlanta, Ga
Reinke, E. E., 15124 S.E. 43, Bellevue, Wash.
Rogers, L. E., 4518 Cleveland, Kansas City 30, Mo.
Rosenstein, M., 4528—215 Pl., Bayside, L. I., N. Y.
Rosenthal, M. H., 44 Highland St., Sharon, Mass.
Russell, D. H., 649 Hoey Ave., Longbranch, N. J.
Rust, M. F., 4837 Avondale Dr., Fort Wayne 5, Ind.

(*Continued on page 66A*)

ring up production savings with Hermetic mechanical assemblies

Eliminates a costly production step!

Every production step saved *is money saved!* And production savings increase steadily with every Hermetic Mechanical Assembly used. The integrally glassed assembly terminals eliminate the soldering of terminals to enclosure covers. To the manufacturer, this means a profit increase!

Hermetic Vac-Tite* Seals are available in an unparalleled selection of mechanical designs that provide maximum economy and mounting security.

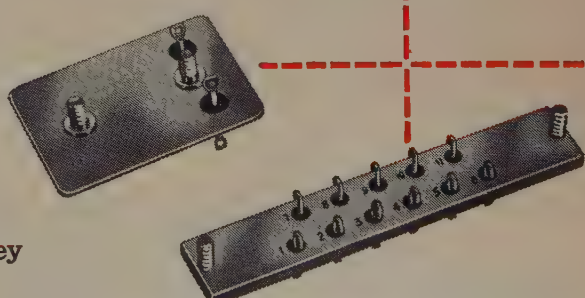
If requirements call for unit headers—Hermetic can supply them with studs attached, shaped to fit enclosures or cans.

For problems concerning terminal strips—Hermetic can provide terminal strips with or without studs and special mounting features, with integrally glassed terminals that offer the advantages of the arc-resistance of glass, and one-piece assembly, modular construction.

Whatever the problem in mechanical assemblies, whether it be color-coded terminal plates, lock-ring safety seals, or attached bracket seals—specially designed Hermetic Vac-Tite* Seals can furnish the money-saving solution to your problem.

Write for engineering assistance, data, and prices.

*Vac-Tite is Hermetic's new vacuum-proof, compression construction glass-to-metal seal.



SEALED IN by HERMETIC HEADERS

Hermetic Seal Products Company

29 South 6th Street, Newark 7, New Jersey

FIRST AND FOREMOST IN MINIATURIZATION

Membership

(Continued from page 64A)

Ryan, F. A., United Aircraft Products, Inc., 1116 Bolander Ave., Dayton, Ohio
Ryan, P. J., 7 Druid Ct., Tuscaloosa, Ala.
Rymsha, A. F., 26 Longfellow Dr., Rahway, N. J.
Sallus, G. M., 1045 Wahler Pl., S.E., Washington 20, D. C.
Sanders, S., 3410 N.W. Seventh Ave., Miami, Fla.
Sato, R. H., 1548 Glen Ave., Wahiawa, Oahu, T. H.
Sawyer, C. E., 512 Main St., Acton, Mass.
Schlaeppi, H. P., Dipl El. Ing. ETH, Rigistrasse 31, Zurich 6, Switzerland
Schoenduve, H. W., Westron Sales & Engineering, 7407 Melrose Ave., Los Angeles 46, Calif.
Schulz, F. J., 289 Beechwood Ave., Union, N. J.
Schunneman, R. F., Bell Telephone Laboratories, Inc., 463 West St., New York 14, N. Y.
Scofield, B. L., 541 Monticello Dr., Falls Church, Va.
Shapiro, H., c/o General Delivery, Haselton Branch, Rome, N. Y.
Shapiro, S., 855 N. Detroit St., Los Angeles, Calif.
Sherburne, R. K., Box 946, State College, N. Mex.
Shirley, J. N., 7400 Hardy, Overland Park, Kans.
Silverberg, A., 1475 President St., Brooklyn 13, N. Y.
Smith, G. A., 11431—63 St., Edmonton, Alta., Canada
Smith, W. M., 1420 Saltair Ave., Los Angeles, Calif.
Smyton, S. A., 5820 Baltimore Ave., Philadelphia 48, Pa.
Sroufe, S. J., Jr., 1116 N.W. 40, Oklahoma City 18, Okla.
Staats, R. U., 4208 N. 45 Pl., Phoenix, Ariz.
Stites, R. S., 4002 N. 48 Pl., Phoenix, Ariz.
Stoughton, P. N., Treetops La., Poughkeepsie, N. Y.
Sullivan, O. J., 4008 Cresthaven Rd., Dallas, Tex.
Swank, D. A., Electronics Dept., High Energy Physics Laboratory, Stanford University, Stanford, Calif.
Swanson, E. S., 4925 Gaywood Dr., Fort Wayne, Ind.
Theall, C. E., Jr., Cold Springs Rd., R.F.D., Liverpool, N. Y.
Thomas, W. M., 5935 S. Justine St., Chicago 36, Ill.
Thompson, D. I., 4517 Leeds St., El Paso, Tex.
Thurmond, F. S., Jr., 6000 Lemmon Ave., Dallas, Tex.
Tiller, R. W., 12—11234—116 St., Edmonton, Alta., Canada
Trump, B. C., 6009 Green Tree Rd., Bethesda, Md.
Visotsky, V. M., 3834 Evans St., Los Angeles, Calif.
Vlach, G., 1934 S. 60 Ct., Cicero, Ill.
Wagner, N., 1765 S. Alamo, Las Cruces, N. Mex.
Wait, W. H., 7726 Joplin St., Houston 17, Tex.
Wallis, J. C., 2406 Kelly Ave., Gulfport, Miss.
Ward, J. R., III, 6332nd Fld. Maint. Sqdrn., Box 512, APO 239, San Francisco, Calif.
Weissman, N., c/o Engineering WLWD-TV, 4595 S. Dixie Hgwy., Dayton 9, Ohio
Whiteside, J. R., 594 Summerdale Ave., Glen Ellyn, Ill.
Wolf, H. S., 3811 Oakford Ave., Baltimore 15, Mo.
West, T. J., 1133 Mary St., Elizabeth, N. J.
Whitacre, J. W., 2313 Alpha St., Lansing, Mich.
Whiteside, R. L., 4450 Quensnelle Dr., Vancouver 8, B. C., Canada
Wiant, W. E., 3215 Hursh Pl., N.W., Canton 8, Ohio
Williams, F. K., 10357 De Soto Ave., Chatsworth, Calif.
Wines, A. J., Sr., 667 S. Seventh Ave., Mt. Vernon, N. Y.
Wolkon, D., Superior Magneto Corp., 3B-06—19 Ave., Long Island City 5, L. I., N. Y.
Wylie, A., 12611—124 St., Edmonton, Alta., Canada
Yoshizuka, R. K., Box 9049 TAS, Fort Bliss, Tex.
Yourke, H. S., 9 Wainwright Ave., Yonkers 2, N. Y.
Ziegler, A. A., C.M.R. 105, Peoria, Ill.

(Continued on page 68A)

FOR ALL Ku-BAND APPLICATIONS SPECIFY THE FINEST KLYSTRON...

VARIAN'S NEW VA-94

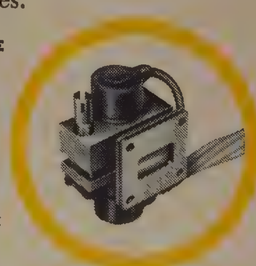
Varian now offers the most advanced reflex klystron ever developed for airborne radar local oscillator and beacon service. *The VA-94* provides a minimum power output of 20 mw throughout its range of 16 to 17 kmc . . . to give you absolutely reliable operation at any altitude without pressurization.

Exclusive Varian features include a unique brazed-on external tuning cavity . . . to assure you of excellent frequency stability, extremely low microphonics, slow tuning rate and long tuning life. Its single screw tuner adapts easily to motor tuning. The VA-94 weighs only four ounces and mates directly with standard waveguide flanges.

TYPICAL OPERATION

Frequency	*16.5 kmc*
Resonator Voltage	*300 v*
Resonator Current	*38 ma*
Reflector Voltage	*−150 v*
Power Output (VSWR < 1.1)	*40 mw*
Electronic Tuning	*65 mc*

FOR EXPERIMENTAL APPLICATIONS . . . SPECIFY THE VERSATILE NEW VA-92. Varian's VA-92 meets all reflex oscillator requirements in the frequency range 14 to 17.5 kmc . . . is especially suitable for signal generators and laboratory testing. It gives you the ease of tuning, ruggedness and reliable performance that has made Varian klystrons the first choice among microwave engineers. Special features include linear reflector voltage tracking, wide tuning range and high altitude operation without pressurization.



FOR OTHER K-BAND APPLICATIONS . . . SPECIFY V-39, V-40 AND VA-96.

FOR COMPLETE SPECIFICATIONS and technical data on the outstanding new VA-94, and other Varian klystrons, contact our Application Engineering Department.

IN KLYSTRONS, THE MARK OF LEADERSHIP IS

VARIAN associates

PALO ALTO 2, CALIFORNIA

Representatives in all principal cities

Membership

(Continued from page 66A)

The following transfers and admissions were approved to be effective as of March 1, 1955:

Transfer to Senior Member

Aldrich, D. F., 1030 Hoffman St., Elmira, N. Y.
Bawer, L. I., 16-27 Eberlin Dr., Fair Lawn, N. J.
Beier, M. G., 440 Fairfield Ave., Elmhurst, Ill.
Benson, M. C., Box 1316, Shreveport, La.
Bidlack, C. S., 14 Gregory Hall, Urbana, Ill.
Boltz, H. A., 18069 Outer Dr., Dearborn, Mich.
Brachman, M. K., 2237 Republic National Bank Bldg., Dallas 1, Tex.
Brent, L. L., 1330 N. Newstead Ave., St. Louis 13, Mo.
Brooks, J. F., Box 1042, U. S. Naval Station, Key West, Fla.
Carman, W. H., 2701 Parsifal, N.E., Albuquerque, N. Mex.
Chapin, E. W., 6 Fairfield Dr., Catonsville 28, Md.
Cleveland, W. C., Jr., 4644 Dana Dr., La Mesa, Calif.
Conrad, E., 9027 Molly Woods Ave., La Mesa, Calif.
Copeland, W. H., 11188 Ophir Dr., Los Angeles 24, Calif.
Cotsworth, A., III, 809 Linden Ave., Oak Park, Ill.
Criss, G. B., Box 208, R.F.D. 2, Lansdale, Pa.
Deerhake, W. J., Watson Laboratory, 612 W. 115 St., New York 27, N. Y.
Githens, T. A., Zenith Radio Corp., 6001 W. Dickens Ave., Chicago 39, Ill.
Golden, N. J., 161 Topsfield Rd., Ipswich, Mass.
Gorbunoff, A., 219 N. Yale Ave., Villa Park, Ill.
Graber, R. E., Box 783, San Fernando, Calif.
Graham, R. W., Graham Electronic Products Co., 6502 E. Cooper St., Tucson, Ariz.
Gray, R. O., 2305 S. 16 Ave., Broadview, Ill.
Green, J. S., 6422 Wynkoop St., Los Angeles 45, Calif.
Guerrero, E. S., 115 Witmer St., Los Angeles 26, Calif.
Hayt, W. H., Jr., Electrical Engineering School, Purdue University, W. Lafayette, Ind.
Kups, E. F., 552 S. 19 St., Newark 3, N. J.
Langford, R. C., 920 Adams Ave., Elizabeth, N. J.
Larkin, K. T., Box 359, Wayland, Mass.
Larsen, F. J., Honeywell Research Center, 500 Washington Ave., S., Hopkins, Minn.
Lindeman, B., 419 Randolph St., Huntsville, Ala.
Loth, P. A., 11 Wishing La., Hicksville, L. I., N. Y.
Loughlin, R. G., 31 Laurel Dr., New Hyde Park, L. I., N. Y.
Moynahan, G. F., Jr., Box 582, Fort Huachuca, Ariz.
Nordby, R. M., 1860 Sherman Ave., Evanston, Ill.
O'Donnell, R. J., 412 Westgate Rd., Baltimore 29, Md.
Peterson, A. W., 150 Elmwood Ct., Emporium, Pa.
Raybin, M. W., 1373 E. Kingsley Ave., Pomona, Calif.
Reedy, P. H., 1742 Grevalia St., Apt. E, S. Pasadena, Calif.
Reiche, H., 235 Cooper St., Ottawa, Ont., Canada
Riepka, H. C., Kaiserstr. 23, Porz/Rhein (22c), Germany
Robinson, L. P., 1438 Loma Vista, Pasadena, Calif.
Rohde, L., 7 Tassiloplatz, Munchen 9, Germany
Ruze, J., 231 Beacon St., Boston, Mass.
Salz, N. P., Sylvania Electric Products, Inc., Bayside, L. I., N. Y.
Scheneman, E. E., 412 Oak Ct., Baltimore 28, Md.
Scheraga, M. G., 29 Westview Rd., Verona, N. J.
Snelling, E. A., 5930 S. Kingsington Ave., LaGrange, Ill.
Steen, W. J., 5442 N. Lamon Ave., Chicago 30, Ill.
Stewart, C., 2711 Wilson Ave., S.W., Cedar Rapids, Iowa

(Continued on page 71A)

(Continued from page 68A)

Stroh, W. J., Tower Lakes, Barrington, Ill.
Vincent, H. F., 305 Edgewood Dr., Huntsville, Ala.
Wade, E., 5337 E. Falls View Dr., San Diego 15, Calif.
Wilkinson, W. C., RCA Laboratories, Princeton, N. J.
Winkler, E. H., 1004 Elm St., Rome, N. Y.

Admission to Senior Member

Beck, J. J., 537 Achille Rd., Havertown, Pa.
Beckman, J. A., 11345 Rudman Dr., Culver City, Calif.
Behn, E. R., 11 Elm St., Garden City, L. I., N. Y.
Brough, J. R., Borton Landing Rd., Moorestown, N. J.
Clementson, G. C., 316 Dawnview Ave., Dayton 3, Ohio
Eaves, H. H., 1575 E. Valley Rd., Santa Barbara, Calif.
Edmunds, E. E., 55 Queen Anne Dr., Shrewsbury, N. J.
Eigner, H., 31 Daffodil La., Levittown, Pa.
Feldmann, F., 17 Hillside Ave., Roslyn Heights, L. I., N. Y.
Fishbein, M., 2684 West St., Brooklyn 23, N. Y.
Glickman, M. N., 29-37 S. Sixth St., Newark 7, N. J.
Goffi, G., 18 bis Via Verres 18 bis, Torino (811), Italia
Gray, G. E., 3908 Johnson St., Western Springs, Ill.
Hammack, C. M., 1651 Tulane Dr., Mountain View, Calif.
Jenssen, M., Norges tekniske hogskole, Trondheim, Norway
Johnson, J. K., 1968 Park Pl., Lancaster, Pa.
Jones, H. J., 6000 Lemmon Ave., Dallas 9, Tex.
Kott, W. O., 235 E. Bruce Ave., Dayton 5, Ohio
Lee, Y. W., Electrical Engineering Department, Massachusetts Institute of Technology, Cambridge, Mass.
Loeb, J. M., Box 550, Schlumberger Instrument Co., Ridgefield, Conn.
Mattox, C. E., 209 Beverly Rd., Cocoa, Fla.
McDavid, J. A., Headquarters, Northeast Air Command, (Dir/Comm), APO 862, New York, N. Y.
Morgan, S. P., Bell Telephone Laboratories, Murray Hill, N. J.
Pelham, K. F., 34 Bobrich Dr., Rochester 10, N. Y.
Price, M. A., 418 S. Carlyn Spring Rd., Arlington, Va.
Pulles, J. H., 1615 Washington St., Evanston, Ill.
Reynolds, G. W., 3975 Orange Dr., Los Angeles 56, Calif.
Sabbagh, E. M., 1800 Garden St., W. Lafayette, Ind.
Schuler, R. G., Victor Adding Machine Co., 3900 N. Rockwell St., Chicago 18, Ill.
Spindler, C. W., Jr., 617 Arlingham Rd., Flourtown, Pa.
Suits, C. G., Box 1088, General Electric Research Laboratory, Schenectady, N. Y.
Watson, R. D., 9323 Wire Ave., Silver Spring, Md.
Weber, D. W., 396—21 St., S.E., Cedar Rapids, Iowa
Wood, M. R., 108 E. 38 St., New York 16, N. Y.
Young, C. M., General Electric Co., 1 River Rd., Bldg. 269, Schenectady 5, N. Y.

Transfer to Member

Allison, D. B., 727 E. Third St., Hastings, Nebr.
Barringer, E. E., 4612 E. Eastland, Tucson, Ariz.
Berliner, J., 100 Ringdahl Ct., Rome, N. Y.
Bernard, H. F., 3670 S.W. Ninth Ter., Miami, Fla.

(Continued on page 72A)

Membership

(Continued from page 71A)

Bernstein, E., 909 W. University Pkwy., Baltimore 10, Md.
Bowen, H. C., Box 202, Warren, R. I.
Buck, D. T., 37-41 Marcy St., Freehold, N. J.
Bunker, W. M., 1702 Hermosa Ave., Apt. 8, Hermosa Beach, Calif.
Busching, H. L., 100 Carpenter Ave., Sea Cliff, L. I., N. Y.
Bussgang, J. J., 185 Hancock St., Cambridge 39, Mass.
Cannizzaro, M., 22 Division St., Waterbury 36, Conn.
Caquelin, M. W., 616—26 St., S.E., Cedar Rapids, Iowa
Christiansen, D., 12 Hay St., Newbury, Mass.
Coble, R. B., 645—34 St., S.E., Cedar Rapids, Iowa
Colletti, N., 783 S. Hawkins Ave., Akron 20, Ohio
Connally, R. E., 515 Cottonwood Dr., Richland, Wash.
Cottle, D. W., Doyle Rd., R.F.D. 3, Baldwinsville, N. Y.
Craine, W. P., 3758 N. Pacific Ave., Chicago 34, Ill.
Crane, R. L., 528 Ann La., Levittown, L. I., N. Y.
Dale, P. R., RCA Service Co., Government Service Division, Gloucester, N. J.
De Janovich, C. R., 5034 Farwell Ave., Skokie, Ill.
Dickinson, I. E., McClatchy Broadcasting Co., Seventh and Eye Sts., Sacramento, Calif.
Dresser, S. R., Jr., 104 Elmwood Ct., Emporium, Pa.
Ellis, P. V., 6334 N. Missouri Ave., Portland 11, Ore.
Ertman, R. J., 127 Galveston St., S.W., Washington 24, D. C.
Espenlaub, W. C., 56 Hillside La., E., Syosset, L. I., N. Y.
Falkenbach, G. J., Lee Laboratories, Inc., Genesee, Pa.
Flashner, G., 24 East St., Beverly, Mass.
Friedman, D., "Caprice" Long Hill Rd., Oakland, N. J.
Glomb, W. L., 39 Surrey La., Clifton, N. J.
Hamann, K. R., Cleveland Recording Co., 1515 Euclid Ave., Cleveland 15, Ohio
Hevesh, A. H., 79-50 Langdale St., New Hyde Park, L. I., N. Y.
Hiebert, R. D., 1792—37 St., Los Alamos, N. Mex.
Horowitz, J., 2682 W. Second St., Brooklyn 23, N. Y.
Howard, D. D., 4230 Oak La., S.E., Washington 22, D. C.
Johnson, L. B., Range Instrumentation Dept., NAMTC, Point Mugu, Calif.
Johnson, W. F., 1062 Portola Dr., Monterey, Calif.
Larsen, R. L., 5943 N. Warnock St., Philadelphia 41, Pa.
Luongo, J., 23 Upland Way, Cedar Grove, N. J.
Machlis, J., 17245 Lahey St., Granada Hills, Calif.
Makleff, P., 1 Haifa Rd., Tel Aviv, Israel
Mitoma, E. Y., 6658—13 St., N.W., Washington 12, D. C.
Montgomery, D. N., 4219 Lynd Ave., Arcadia, Calif.
Moyer, J. N., 3235 Norwalk Dr., Dallas 20, Tex.
Norwood, C. A., 830 Gales Ave., Winston Salem, N. C.
Oettinger, A. G., Computation Laboratory, Harvard University, Cambridge 38, Mass.
Ossman, E. A., 3 Juniper St., Rochester 10, N. Y.
Piskor, J., 1000 Capitol Ave., Hartford 6, Conn.
Puckett, T. H., 410 N.E. 14 St., Oklahoma City, Okla.
Quist, W. G., 103 Williston, Wheaton, Ill.
Rabin, R., 105-34—65 Ave., Forest Hills, L. I., N. Y.
Reiling, G. E., 2226 Winston Ave., Louisville 5, Ky.

(Continued on page 75A)

(Continued from page 72A)

Robertson, G. R., 717 N. Lake Ave., Pasadena 6, Calif.
Schreiner, R. J., 34 Pier St., Yonkers 5, N. Y.
Simmons, D. J., 4305 Fairfax, Fort Worth, Tex.
Stastny, G. F., 202 W. Walnut St., Alexandria, Va.
Stone, R. M., 1816 Puritan Dr., Irving, Tex.
Sutton, A. T., 3913 Cross Creek Rd., Nashville 12, Tenn.
Tannenbaum, D. A., 1025 Collings Ave., W. Collingswood, N. J.
Thayer, J. W., 4553 W. 150 St., Cleveland 11, Ohio
Vehslage, E. P., 14 Stoner Ave., Apt. 33K, Great Neck, L. I., N. Y.
Vick Roy, J. W., 223 Pembrook Ave., Morrestown, N. J.
Walance, C. G., 200 Via Colorin, Palos Verdes Estates, Calif.
Ward, D. L., 1914 Beach St., Winston-Salem, N. C.
Williams, R. L., 2705 University Dr., Durham, N. C.
Willsey, R. H., 1877 Chaucer Dr., Cincinnati 37, Ohio
Yarosh, N. P., Goodyear Aircraft Co., Akron, Ohio

Admission to Member

Anderson, W. W., 905 S. Tenth St., Burlington, Iowa
Archibald, W. R., Box 387, Alamogordo, N. Mex.
Backus, J. W., I.B.M., 590 Madison Ave., New York, N. Y.
Barbeau, A. R., 314 Knoedler Rd., Pittsburgh 36, Pa.
Barton, B. F., Cooley Bldg., University of Michigan, Ann Arbor, Mich.
Bayliss, R. E., 11 Robert Ave., Woburn, Mass.
Beckman, D. L., 359 Highland St., South Amboy, N. J.
Beidler, R. T., 303 Ruby St., Lancaster, Pa.
Bohr, E. T., 1708 McAllister Dr., Huntsville, Ala.
Brewster, P. J., 92 E. Logan St., Philadelphia 44, Pa.
Brown, D. J., Hq. NEAC D/Comm Opns, APO 862, c/o Postmaster, New York, N. Y.
Brown, E. R., Jr., Philco Corp., Tioga and "C" Sts., Philadelphia, Pa.
Buckner, G. O., Jr., 1628 Old Spanish Trail, Houston 25, Tex.
Bugeja, A. A., 6, Leighton Pl., London N.W. 5, England
Burgess, E. G., Jr., 83-47—116 St., Kew Gardens, L. I., N. Y.
Burns, W. E., Rombout Ridge, Poughkeepsie, N. Y.
Busch, C. W., 19 Holbeinstrasse, Bremen, American Zone, Germany
Byrd, D. J. P., International Telemeter Corp., 2000 Stoner Ave., Los Angeles 25, Calif.
Cali, L. W., 717 N. Lake Ave., Pasadena 6, Calif.
Campbell, W. O., 515 Walker Ave., Baltimore 12, Md.
Christianson, L. F., Electronic Associates, Inc., Long Branch, N. J.
Colistra, W. P., Sperry Gyroscope Co., Great Neck, L. I., N. Y.
Collins, W. H., 2302 Lee Hiwy., Apt. 304, Arlington, Va.
Constable, R. C., 84 Chestnut Ave., Floral Park, L. I., N. Y.
Coombs, W. F., Jr., 25 Longview Ter., Rochester 9, N. Y.
Cork, H. A., 1607 E. Newport Ave., Nilwaukee 11, Wis.
Corwin, J. J., 77 Stonecutter Rd., Levittown, L. I., N. Y.
Cringan, F. J., c/o Canadian Aviation Electronics, Ltd., 387 Sutherland St., Winnipeg 4, Manit., Canada
Crockett, G. R., 419 W. 49 St., Indianapolis, Ind.
Cronin, H. C., 1730 Newton Rd., WTVD, Box 2009, Durham, N. C.

(Continued on page 76A)

Membership

(Continued from page 75A)

Cushing, R. E., 5016 Lindsay Rd., S.E., Washington 21, D. C.
Davies, J. A., 1774 Griffith Ave., Owensboro, Ky.
Deaderick, G. E., 6000 Lemmon Ave., Dallas 9, Tex.
Deavenport, J. E., 2214 Berwyn Dr., St. Louis 21, Mo.
Deininger, C. F., 2609 W. 112 St., Inglewood 4, Calif.
Diamond, A., 80-08—45 Ave., Elmhurst, L. I., N. Y
DiFusco, F. J., 7 Micieli Pl., Brooklyn 18, N. Y.
Ehrlich, C. I., 1624 N. Farwell, Milwaukee 2, Wis.
Fisk, W. J., 3606 S. Ewing, Dallas 16, Tex.
Fitzgerald, J. J., 11 Brookford St., Cambridge 40, Mass.
Fix, W. G., Carborundum Co., Globar Division, 3335 W. 47 St., Chicago 32, Ill.
Fogelberg, A. E., 2812 Benson St., Camden, N. J.
Gahn, E. H., 7814 Maplewood Ind. Ct., St. Louis 17, Mo.
Garner, W. E., 6405—Eighth Ave., Hyattsville, Md.
Garten, L. A., c/o Louis A. Garten & Associates, 25 Valley Rd., Montclair, N. J.
George, R. E., 27 Oldert Dr., Pearl River, N. Y.
Girerd, J. L. M., 24 Boulevard Raspail, Paris 7ieme, France
Gonzalez-Correa, E., 133 Rumson Rd., Little Silver, N. J.
Gregory, C. A., Jr., Box 1-F, Richmond, Va.
Grossman, H. W., Box 912, Fort Huachuca, Ariz.
Hall, G. N., General Electric Co., Engineering Department, Clyde, N. Y.
Harder, D., 110-45 Queens Blvd., Forest Hills, L. I., N. Y.
Havens, J. D., 124 Grand St., Burlington, Iowa
Hesse, J. F., 719 Lenrey Ave., El Centro, Calif.
Hinds, W. C., Jr., 14 Turner St., Presque Isle, Me.
Hiser, E. F., Jr., Bendix Radio, McClellan, Calif.
Hixson, W. C., 5503 Mayfair Dr., Forest Pk., Pensacola, Fla.
Hogg, F. L., 37 Stormont Rd., Highgate, London N.6, England
Hurlbut, J. F., 2240 S. Adams St., Denver 10, Colo.
Israel, F., 1034 Maplewood Dr., Falls Church, Va.
Johnson, M. D., 803 Northview St., Tullahoma, Tenn.
Jones, M. E., 901 N. Third St., Burlington, Iowa
Katz, H. W., General Electric Electronics Laboratory, Rm. 119, Bldg. 3, Syracuse, N. Y.
Kay, A. F., 474 Richmond Ave., Maplewood, N. J.
Kay, D. H. J., 4660 Peter St., S. Burnaby, B.C., Canada
Kernan, P., 32 Dunvale Rd., Towson 4, Md.
Kinsman, R. B., 1315 Second Ave., S.W., Waverly, Iowa
Knowles, R. D., 867 Southern Blvd., New York 59, N. Y.
Kramer, R., 6 Norfolk Ter., Dorchester 24, Mass.
Laudon, H., 39-25—51 St., Woodside 77, L. I., N. Y.
Lawless, J. H., USS Newport News (CA 148), c/o FPO, New York, N. Y.
Lewis, E. M., III, 34 School La., Strafford, Wayne, Pa.
Lodge, C. R., San Diego State College, San Diego 15, Calif.
Lofgren, F. W., 58 Hume Ave., Medford 55, Mass.
Loposer, T. L., 3543 S. Ewing Ave., Dallas 16, Tex.
Ludekens, L. E., 621 N. Hidalgo Ave., Alhambra, Calif.
McManus, R. P., 2752 Nipoma St., San Diego 6, Calif.
Meissinger, H. F., Guided Missile Division, Hughes Research & Development Laboratories, Culver City, Calif.
Mendelson, B. G., 2643 W. Balmoral Ave., Chicago 25, Ill.

(Continued on page 78A)

THERE ARE NONE FINER!
TRU-OHM
Power
RHEOSTATS
TRU-OHM POWER RHEOSTATS
are more and more in demand and
there are many reasons. These
include finest quality, better service,
and delivery; UL approval; variety from
25 watts up; fairest prices; AND TRU-OHM
expedites for YOU . . . TRU-OHM ships on time.
We invite your inquiry.
Have you received our latest catalog? WRITE TODAY!
TRU-OHM PRODUCTS
Division of
Model Engineering
& Mfg., Inc.
General Sales Office: 2800 N. Milwaukee Avenue, Chicago 18, Ill.
Factory: Huntington, Indiana
"Largest producers of wire-wound resistors in the U.S.A."
MANUFACTURERS: Power Rheostats, Fixed Resistors, Adjustable Resistors, "Econohm" Resistors, "Tru-rib" Resistors

Membership

(*Continued from page 76A*)

Moldoff, S., 31 Winnetou Rd., White Plains, N. Y
Mowatt, A. Q., Box 466, Bedford, Mass.
Nardone, L. J., 76 Woodside Ave., Winthrop 52, Mass.
Neal, J. P., III, 921 W. Daniel St., Champaign, Ill.
Neira, T. M., Apartado Nacional 3252, 40-22 Calle 25A, Bogota, Colombia, S. A.
NeSmith, W. W., Box 272, Mojave, Calif.
Newton, C. E., Jr., 840 Woodington Rd., Baltimore 29, Md.
Noll, R. E., 1715 B. Waverly Way, Baltimore 12, Md.
O'Hare, W. S., 1315 St. Paul St., Baltimore 2, Md.
Orrick, T. W., Box 547, Williams Rd., Rome, N. Y.
Paul, K. R., c/o Addison Industries, 9-II Hanna Ave., Toronto 1, Ont., Canada
Peterson, C. A., R.F.D. 1, Smethport, Pa.
Pollard, R. E., 2135 Franklin Ave., E. Meadow, L. I., N. Y.
Pound, A. W., 3300 Chenu Ave., Sacramento 21, Calif.
Ramos, E., 3513—20 St., N.E., Washington 18, D. C.
Regis, R., 69-25—182 St., Flushing, L. I., N. Y.
Ruckstuhl, C. E., Jr., Old Range Rd., Wilton, Conn.
Rudolph, J. A., 395 Beechwood Dr., Akron 20, Ohio
Schaefer, L. E., 555 Broadway, Hastings-on-Hudson, N. Y.
Schuder, J. C., School of Electrical Engineering, Purdue University, Lafayette, Ind.
Sloan, J. E., 20 Wayne Gardens, Collingswood 7, N. J.
Smith, G. P., Corning Glass Works, Walnut St., N. Y.
Smith, I. A., Jr., 129 Brucemont Cir., Asheville, N. C.
Smith, W., 505 Emerick St., Ypsilanti, Mich.
Sommer, E. H., Jr., 159 Bickley Rd., Glenside, Pa.
Spitalny, A., 103-19—68 Rd., Forest Hills 75, L. I., N. Y.
Srinivasan, R., 27 Clarendon Rd., London W.11, England
Starr, J. E., 1550 Collingwood St., Detroit 6, Mich.
Steinkamp, W. H., Beckman Instruments, Inc., 2500 Fullerton Rd., Fullerton, Calif.
Sussman, S. M., 409 Beacon St., Boston 15, Mass.
Sutherland, L. C., Speech Department, University of Washington, Seattle 5, Wash.
Thomas, J. A., C&A Department of Commerce, Domestic Airport Terminal Bldg., S. San Francisco, Calif.
Thompson, R. L., 3571 Bodega Ct., Sacramento 21, Calif.
Toscano, P. M., 122 E. Wayne Ter., Collingswood 7, N. J.
Traver, H. R., 10 Catherine St., Lynbrook, L. I., N. Y.
Tucker, S. M., 3302 Carolina Pl., Alexandria, Va.
Tutwiler, K. E., 1500 Bel-Aire Dr., Belleville, Ill.
Wagner, W. O., 2106 A. N. 16 St., Milwaukee 5, Wis.
Waldner, R. G., 41 Apple Tree La., Belleville, Ill.
Walker, R. G., 478 Tremont Ave., Orange, N. J.
Warren, J. D., 935 N. Blaylock Dr., Irving, Tex.
Watson, A. L., 4018 Norfolk, Houston 6, Tex.
White, T. M., Jr., 1015 Lindbergh Dr., N.E., Atlanta, Ga.
Wilder, G. E., 800 Duskin Dr., El Paso, Tex.
Wilson, L. A., Jr , 801 Calle Alvord, Tucson, Ariz.
Winston, A. W., c/o Schlumberger Well Surveying Corp., Box 2175, Houston, Tex.
Wobig, W. H., Gates Ave., Homestead Pk., R.F.D. 1, Chatham, N. J.
Wood, H. R. A., 57, Chiltern Rd., Sutton, Surrey, England
Wright, T. E., 937 S.W. 26, Oklahoma City, Okla.
Yoon, P., 7740 Livingston Rd., S.E., Washington 22, D. C.

(*Continued on page 82A*)

Responsibility for the contents of papers published in the PROCEEDINGS OF THE I.R.E. rests upon the authors. Statements made in papers are not binding on the Institute or its members.

PROCEEDINGS OF THE IRE

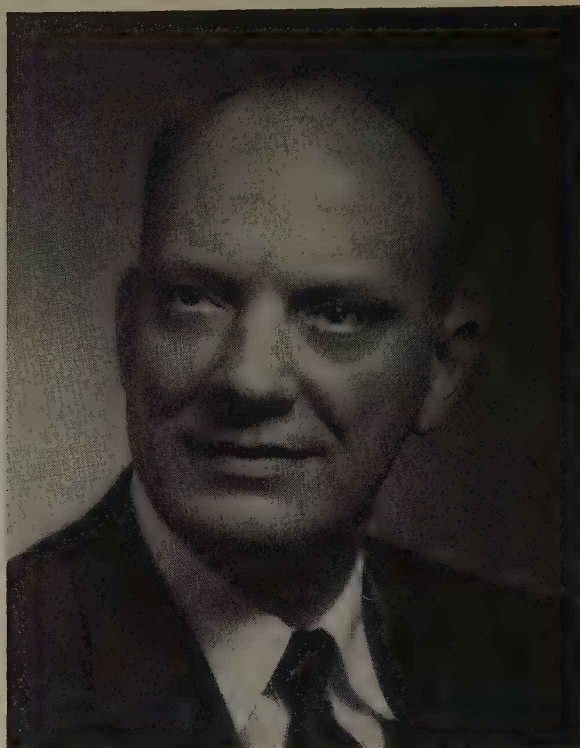
Published Monthly by

The Institute of Radio Engineers, Inc.

VOLUME 43—PART I | *April, 1955* | NUMBER 4

CONTENTS

Change of address (with advance notice of fifteen days) and communications regarding subscriptions and payments should be mailed to the Secretary of the Institute, at 450 Ahnaip St., Menasha, Wisconsin, or 1 East 79 Street, New York 21, N. Y.



John F. Byrne

DIRECTOR, 1955

John F. Byrne was born on October 26, 1905, in Cincinnati, Ohio. He attended Ohio State University, receiving the B.S. degree in Engineering Physics in 1927 and the M.S. degree in Electrical Engineering in 1928.

After a year with the Bell Telephone Laboratories, Mr. Byrne returned to Ohio State as a faculty member; he was Assistant Professor of Electrical Engineering when he left the university in 1937 to join the Collins Radio Company. In 1942, he became associated with the newly formed Radio Research Laboratory at Harvard University, the first laboratory organization to devote its time exclusively to the development of electronic countermeasures equipment and techniques. He was appointed Associate Director of the laboratory in January, 1945. From 1946 to 1950 Mr. Byrne was Vice-President in charge of research and engineering at the Airborne Instruments Laboratory in Mineola, New York. With Motorola since 1950, he was first Director of Engineering for the Communications Division, and is now General Manager of the Riverside Research Laboratory at Riverside, California.

Mr. Byrne has served on several government committees; he was Chairman of the Electronic Countermeasures Panel of the Research and Development Board, 1949–1951, and is currently a member of the Advisory Council for the Army Electronic Proving Ground at Fort Huachuca.

For his work during World War II, Mr. Byrne received the U. S. Navy Certificate of Commendation and the Presidential Certificate of Merit. He is a member of Tau Beta Pi and Eta Kappa Nu.

Mr. Byrne became a Senior Member of the IRE in 1945, and received the Fellow Award in 1950, "for his development of a system of polyphase broadcasting and for effective engineering administration in connection with countermeasures during the war." He has served on various IRE committees including Tellers, 1949, and Awards, 1953–1955.

Index to Abstracts and References

To keep himself reasonably well informed today, the radio engineer must overcome difficulties which could be characterized both as gastronomical and astronomical. He must continually digest large quantities of information about myriad technical developments in a vast and complex field if he is to sustain his professional health and not wither on the vine.

His chief source of nourishment is the technical literature. But here his troubles multiply. There are in existence today at least 1,000 publications in which technical papers related to radio engineering might appear. Hence, he has even greater difficulty in finding the particular nourishment his diet requires than he has in assimilating it.

One of the few outstanding and comprehensive guides to the technical literature is Abstracts and References, which has been reprinted monthly in the PROCEEDINGS since June, 1946 from *Wireless Engineer* in England. This material is compiled from over 200 leading journals by the Department of Scientific and Industrial Research in London for *Wireless Engineer*. Its appearance in PROCEEDINGS has provided readers with an extremely valuable digest of a major portion of the significant contributions to the technical literature.

As valuable as this service has been, its usefulness has been only transitory. The abstracts can be read to great advantage as each issue appears, but once read, their usefulness ceases. There is no ready way of referring back to them at a later date and finding specific information. Thus, a glittering treasure of 30,000 abstracts now lies buried on the bookshelf, beyond the reach of the average reader.

In order that the 3,700 abstracts published last year may be of permanent reference value in the future, an annual index has been reprinted from the March, 1955 issue of *Wireless Engineer* and is published as Part II of this issue of PROCEEDINGS. The index, which is separately bound, has been mailed together with the regular issue (Part I) to all IRE members and subscribers. Since the abstracts are reprinted in PROCEEDINGS one month after they appear in *Wireless Engineer*, the index covers those abstracts which were published in the February, 1954 through January, 1955 issues of PROCEEDINGS.

We are grateful to W. T. Cocking, Editor of *Wireless Engineer*, for his co-operation in providing the material for the index. It is felt that the wide distribution thus afforded the index will add very substantially to the value of an already outstanding service.

—*The Managing Editor*

A Survey of Magnetic Amplifiers*

CARROLL W. LUFCY†

> The following paper is one of a planned series of invited papers, in which men of recognized standing will review recent developments in, and the present status of, various fields in which noteworthy progress has been made.
>
> —*The Editor*

Summary—**This paper was written to present the subject of magnetic amplifiers to those scientists and engineers who have not had an opportunity to observe the progress which has taken place in this field. No detailed technical discussions have been attempted and many aspects of magnetic amplifier operation and applications are only briefly mentioned.**

The basic operation, along with certain fundamental circuits which represent present and potential applications, are discussed with the view in mind of indicating to the reader the range and usefulness of magnetic amplifiers.

Historical Development

THE FIRST practical application of a magnetic amplifier in which actual power amplification was achieved was reported in a paper presented before the Institute of Radio Engineers in 1916.[1] This paper, by Dr. Alexanderson, described the use of such a device to amplify the current from a carbon microphone to control the output of a high frequency alternator for radio telephone transmission. As a result of Alexanderson's developments magnetic amplifier controlled alternators were incorporated in many low frequency transmitting stations constructed during World War I. Many of these installations are in operation in various parts of the world today and are still a major factor in present long-range radio communication.

By the close of World War I the vacuum tube amplifier had established itself as a powerful tool and the magnetic amplifier was pushed into the background. For many years the vacuum tube reigned supreme. Between World War I and the close of World War II, despite a few publications on magnetic amplifiers and issuance of several patents on magnetic amplifier circuitry, very little was done in this country by way of its commercial utilization. Developments in this field were carried forward elsewhere, however, most notably in Germany, with the result that by the end of World War II magnetic amplifiers of good quality were being used extensively in their military equipment. The appearance of such units as servo controllers in Luftwaffe planes, voltage regulators in the V-1 "buzz bombs," and in the stabilization equipment of German naval fire control systems, spurred further development in this field in the post-World War II years. The result is that today the magnetic amplifier has emerged as a device of considerable importance in both military and industrial control systems, and shows promise of taking an ever increasing position of importance in the developments and designs of the future.

The small interest in the application of magnetic amplifiers in this country was not due to a lack of suitable circuitry for, indeed, the patent literature contains a wealth of information on circuits and applications thereof, which dates back to the early 1920's. Rather, the almost complete absence of suitable core materials in commercial quantities, plus the lack of a suitable dry-disc-type rectifier, made the performance of magnetic amplifiers constructed from the available components inadequate for most purposes. The use of superior core materials and the development of the selenium dry rectifier largely account for the present successful utilization of principles and circuits which have been known for years.

Basic Principles of Operation

Fundamentally the magnetic amplifier is a device which utilizes the change in inductive impedance of a winding placed upon a magnetic core when the magnetic core becomes saturated. By using a core material having a highly rectangular B-H loop characteristic, this change in inductive impedance can be made to be quite large and very abrupt. In this manner it is possible, through proper procedures, to make such a reactor—when placed in series with an ac power source and a load—act as a switch between the two. The result is a controller which releases power to the load in a manner analogous to the well-known thyratron-type controller.

The exact method of effecting the control of the reactor flux level, which in turn will determine the time at which saturation occurs, can be quite varied. Also the exact manner of inter-connections between the saturable reactor, main ac supply, and load can assume many configurations. The basic principles of operation, however, remain unchanged.

* Original manuscript received by the IRE, January 7, 1955.
† U. S. Naval Ordnance Laboratory, White Oak, Md.
[1] E. F. W. Alexanderson, "A magnetic amplifier for radio telephony," Proc. I.R.E., vol. 4, pp. 101–120; April, 1916.

A simple magnetic amplifier circuit, the principles of operation of which are easily followed, is shown in Fig. 1. From inspection of this figure it is seen that N_p is the winding on the reactor which controls the flow of power from the main ac power source E_S to the load R_L. This control is effected by a second winding on the reactor N_c which is connected to a control source E_c. It is immediately seen that N_c and N_p are closely coupled by the reactor magnetic circuit; therefore any control signal on N_c must operate against the reflected impedance

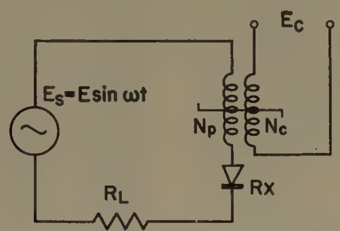


Fig. 1—A simple half-wave magnetic amplifier circuit.

from the winding N_p in effecting a desired flux change in the reactor core. This reflected impedance would normally be very low, thus requiring considerable power from E_c, if it were not for the inclusion of the rectifier element RX in series with N_p. With RX in the circuit there will be one half-cycle of the main ac power source during which the circuit containing N_p is open. During this half-cycle, the impedance reflected from N_p to N_c is very high, and it is possible for a signal from E_c to effect readily a change in flux in the reactor with a small expenditure of power. During the next half-cycle conduction through rectifier RX is permitted. If the internal impedance of E_S and R_L are low, the amount of conduction permitted during this half-cycle will be determined primarily by the inductive impedance of the winding N_p. If the reactor core has a rectangular B-H loop characteristic as shown in Fig. 2, this inductive impedance will be extremely high as long as the reactor core is unsaturated, and very low when saturated. It is immediately apparent that power flowing from E_S through R_L can be controlled by fixing the time during this half-cycle when saturation of the core occurs. This may be accomplished by the control circuit, through N_c, during the preceding half-cycle or "control" period when conduction through RX is prohibited.

If output is obtained during the conducting or "operating" half-cycle, the reactor must be driven into saturation. Then at the beginning of the next half-cycle (or following control period) the reactor flux will return to its remanence position, which is very near saturation for rectangular loop core materials. This is shown as point A in Fig. 2(a). At this time the main power circuit is again opened by rectifier RX (Fig. 1), and power from the signal source E_c may be made to force the flux of the reactor down the loop from the remanence point. The amount of signal can be adjusted to position or "reset" the reactor flux by an amount $\Delta\phi$ to any given point on the loop in accordance with Faraday's Law:

$$\Delta\phi = \frac{1}{N_c}\int E_c dt.$$

Thus, at the beginning of the following half-cycle (or next output half-cycle) the voltage from the supply source which will appear across N_p will cause the reactor to proceed again toward saturation from the level established or reset by the control action. If very little flux reset was accomplished during the control period [as to point B in Fig. 2(a)] the reactor very quickly saturates and most of the supply voltage appears across the load. If a large reset action has taken place [Fig. 2(b)] saturation will occur only during the latter portion of the half-cycle and very little supply voltage will appear across the load. Indeed, if sufficient reset action has occurred, the entire supply source volt-time integral may be absorbed by the reactor and no voltage will appear across the load [Fig. 2(c)]. This represents the cut-off condition and is not exactly zero because a small magnetizing current will always flow through the load in a circuit such as is being discussed.

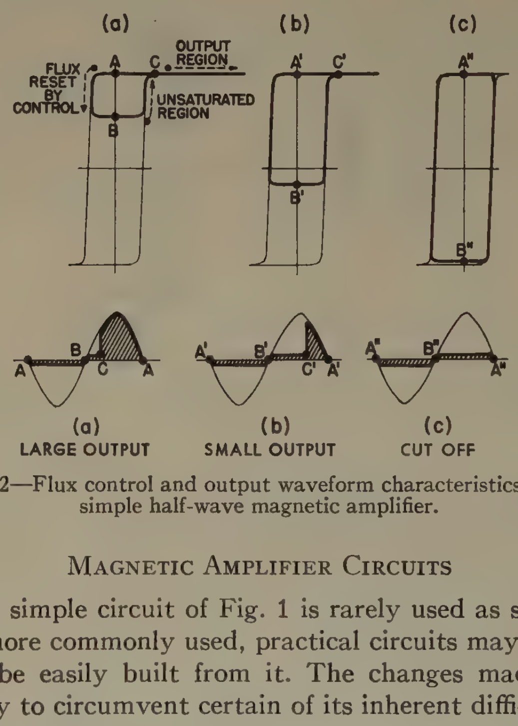


Fig. 2—Flux control and output waveform characteristics of a simple half-wave magnetic amplifier.

Magnetic Amplifier Circuits

The simple circuit of Fig. 1 is rarely used as shown. The more commonly used, practical circuits may, however, be easily built from it. The changes made are usually to circumvent certain of its inherent difficulties or shortcomings. For example, two reactors are generally used in which the N_c windings on each are in series opposition. This cancels fundamental supply frequency voltage which is induced into the control winding by transformer action. It is also evident that only half-wave output is obtained from the circuit of Fig. 1. Full-wave output may be obtained by placing two such circuits back to back. A circuit in which these two changes have been incorporated is shown in Fig. 3 on the following page. This circuit, called the full-wave "doubler" circuit,[2] is one of the most commonly used building

[2] F. G. Logan, "Electric Controlling Apparatus," U. S. Patent 2,126,790, issued August 16, 1938 (application filed June 23, 1936).

blocks in the magnetic amplifier field today.

If a phase reversing output is desired, as for example in a servo controller, two reactors in a bridge arrangement[3] may be used for half-wave output as shown in Fig. 4, or four reactors[4] if full-wave output is desired, as shown in Fig. 5. It is readily seen that the circuit of Fig. 4 is basically two circuits such as in Fig. 1 in a bridge arrangement, while Fig. 5 is two circuits such as in Fig. 3 in a bridge arrangement.

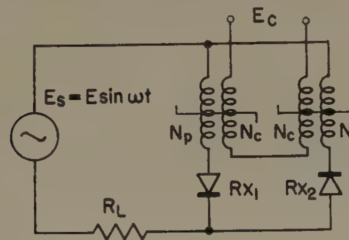


Fig. 3—Full-wave doubler magnetic amplifier circuit.

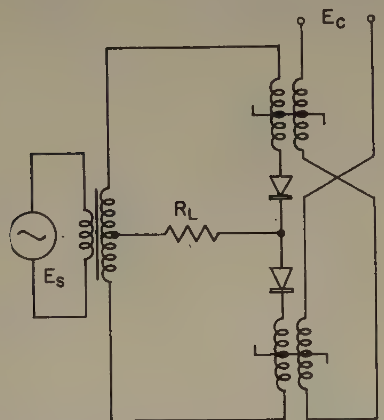


Fig. 4—Half-wave magnetic amplifier circuit with phase reversing output.

Where increased gain or power handling capacity is required these circuits may be cascaded. In a "multistage" amplifier the load of the first stage becomes the control circuit of the second, etc. While larger reactors and rectifiers will generally be used in each succeeding stage, the operation remains basically the same. A typical magnetic amplifier will contain two or three cascaded stages. The exact connections of both the control and power windings depend upon whether an ac or dc signal source is used and upon whether an ac or dc output is desired.

Some requirements may be met by circuits in which the rectifier element (*RX* in Fig. 1) is absent. In this case control is more difficult because it must be effected in the face of a much lower reflected impedance from the N_p windings, as well as induced voltages from the main power source. Such a circuit is shown in Fig. 6. Magnetic amplifiers of this type have low gain but do have an extremely linear transfer characteristic.[5]

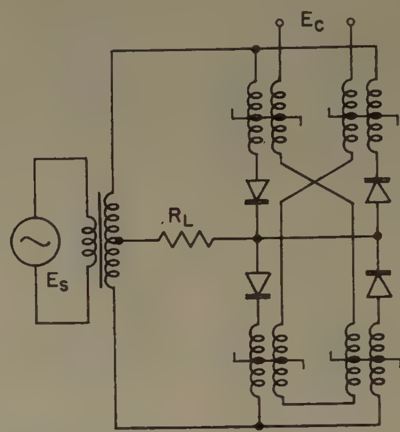


Fig. 5—Full-wave magnetic amplifier circuit with phase reversing output.

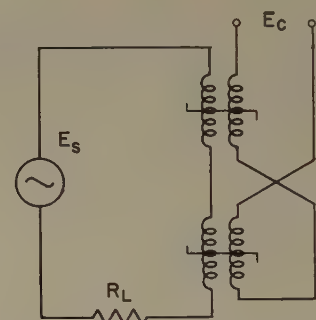


Fig. 6—Simple saturable reactor magnetic amplifier circuit.

Most magnetic amplifiers with a rectifier element in the power winding circuit will, in the absence of any control or bias, immediately proceed into complete saturation and full output. They are therefore called self-saturating amplifiers. In amplifiers without the rectifier element, since both half-cycles of the ac power source voltage appear across the reactor, saturation is brought about only as a result of control action. These are referred to as saturable-reactor amplifiers or "transductors."[6,7] Self-saturating amplifiers are characterized by high gain, a somewhat nonlinear control characteristic, and are sensitive to control voltage polarity (or phase). Saturable-reactor amplifiers have low gain, are very linear, and are insensitive to polarity of control voltage.

It should not be assumed that the inclusion of a rectifier element in the power winding of a reactor is necessary to the basic operation or control of a high-

[3] C. S. Hudson, "Improvements in or Relating to Magnetic Amplifiers," British patent 598,285, issued February 13, 1948 (application filed October 26, 1945).

[4] W. A. Geyger, "Grundlagen der magnetischen Verstärker für die Mess- und Regeltechnik" (Fndamentals of magnetic amplifiers for measurement and control purposes), *Wissenschaftliche Veröffentlichungen aus den Siemens-Werken*, vol. 19, p. 233.

[5] W. J. Dornhoefer and V. H. Krummenacher, "Applying magnetic amplifiers," *Elec. Mfg.*, vol. 45, p. 94; March, 1951; p. 112, April, 1951 is an example.

[6] A. U. Lamm, "Some fundamentals of a theory of the transductor or magnetic amplifier," *Trans. AIEE*, vol. 66, pp. 1078–1085; 1947.

[7] U. H. Krabbe, "The Transductor Amplifier," Lindhska Boktryckeriet, Örebro, Sweden; 1947.

gain magnetic amplifier. Any means whereby the reflected impedances into the control windings may be increased will result in an increase in gain characteristics. Recent circuitry advances have been made in which a combination of a pulse ac source with selective filters replacing the rectifiers has given excellent results.[8]

Speed of Response

From the operation of the circuit in Fig. 1 it is evident that magnetic amplifiers of this type have a limitation on their speed of response which is fundamental. The device controls power, operating on an ac or pulse-type source in such a way that each period of output must be preceded by a period which establishes, through a flux-setting control action, the amount of output to be delivered. These control and output periods are usually one half-cycle in duration, but may both be within the same half-cycle.[9] If they are one half-cycle in duration there will be a minimum delay of one half-cycle of the source frequency per stage of amplification.[10,11] Other factors may contribute to extend this delay over a considerably longer period but in no event can a certain inherent "dead time" be avoided. If faster response is required it is obtained usually by increasing the power source frequency. This may be done by static frequency multiplication[12] of a basic line frequency, by high frequency converters, pulse generating circuits, etc. However, the delay will be decreased only in the same ratio as the amplifier source frequency is increased.

Generally, half-wave circuits will exhibit the minimum dead time or delay of one half-cycle. Full-wave circuits (two half-wave circuits back to back), however, exhibit this minimum delay only under certain conditions. The principal difficulties arise from the fact that it becomes necessary to couple at least two reactors together, either by the control windings, bias windings, or output windings, or combinations thereof, which are in different half-cycles of their basic operation. For example, when one reactor is being controlled or reset the other is being driven into saturation or is delivering output. Voltages induced into windings on the reactor that is in its operating half-cycle will be coupled into the other reactor that is in its control half-cycle. This "feedback" from one reactor to the other is usually in such a direction as to act as an additional aiding control, and hence is positive feedback. This positive feedback action has the advantage of increasing the gain of the circuit but, since it may require several cycles of operation to stabilize, will add to its over-all response time. The full-wave connections also offer many possibilities for circulating currents to flow. These currents will have definite control actions and may have long L/R time constants associated with them. The circuit parameters, core material and rectifier quality determine to a considerable extent the gain versus time delay characteristics of such circuits. It is therefore convenient to express an amplifier's quality in terms of the ratio of its gain to its speed of response. This ratio is called the "figure of merit" of the amplifier,[13] and with present-day core materials and rectifiers can be as great as 5,000 or more.

For half-wave circuits the term "figure of merit" has a limited meaning since the gain and the inherent fixed delay discussed above are not related. The maximum gain of a half-wave circuit, in view of the absence of any positive feedback effects, will be much lower than the gains achievable with a full-wave circuit using identical components. By cancelling the inherent positive feedback effects of the normal full-wave circuit,[14] its response time may be dropped to the same minimum value, but its gain will generally also be dropped to the same order of magnitude as that of the half-wave circuit. The decision as to whether a half-wave or full-wave circuit is desirable will depend largely on the specific application and should be determined only after careful consideration by qualified engineers.

Combination Circuits

Combinations of vacuum tubes or transistors and magnetic amplifiers are frequently used to accomplish results which would not be possible with magnetic amplifiers alone. Almost without exception these combination circuits use vacuum tube or transistor input stages driving magnetic amplifier output stages. In this way gain or high input impedance requirements may be easily met with a suitable input stage while power output requirements are met with a magnetic amplifier stage. Since most of the vacuum tube failures encountered in practice are in the power handling or output stages, a marked increase in over-all reliability may be achieved. Furthermore, the requirements for a large B+ or plate supply source is eliminated by using magnetic amplifier power stages which operate directly from the main ac power source. In many instances this will result in over-all decrease in amplifier size and weight. Fig. 7 (next page) shows typical combination circuit where use of push-pull vacuum tube driver stage controls saturable reactor-type magnetic amplifier output stage. Transistor input stages may be used to advantage in place of vacuum tube stages. A typical transistor-magnetic amplifier

[8] R. E. Morgan and J. B. McFerran, "Pulse Relaxation Amplifier—A Low Level D-C Magnetic Amplifier," AIEE Technical Paper 54-198 presented at the AIEE Northeastern District Meeting, Schenectady, N.Y., May 5–7, 1954.

[9] F. Hill and J. A. Fingerett, "Fast-response magnetic servo amplifier," *Electronics*, vol. 27, pp. 170–173; October, 1954.

[10] R. A. Ramey, "On the mechanics of magnetic amplifier operation," *Trans. AIEE*, vol. 70, part II, pp. 1214–1223; 1951.

[11] C. W. Lufcy, A. E. Schmid, and P. W. Barnhart, "An improved magnetic servo amplifier," *Trans. AIEE*, vol. 71, part I, pp. 281–289; 1952.

[12] J. J. Suozzi and E. T. Hooper, "An all magnetic audio amplifier system," *Trans. AIEE*. Paper 55-70, for presentation at the Winter General Meeting, New York City, January 31–February 5, 1955 is an example.

[13] J. T. Carleton and W. F. Horton, "The figure of merit of magnetic amplifiers," *Trans. AIEE*, vol. 71, part I, pp. 239–245; 1952.

[14] W. A. Geyger, "Magnetic amplifiers of the self-balancing potentiometer type," *Trans. AIEE*, vol. 71, part I, pp. 383–395; 1952. also D. G. Scorgie, "Fast response with magnetic amplifiers," *Trans. AIEE*, vol. 72, part I, pp. 741–749; 1953.

combination appears in Fig. 8 below, where transistor input drives a half-wave bridge phase-reversing, self-saturating magnetic amplifier stage.[15]

Both the vacuum tube and transistor stages require a source of dc power to obtain best performance. They are usually less efficient over-all and at present are less reliable than a magnetic amplifier. These factors, nevertheless, are not serious for low-level stages. Such combinations therefore represent an ever increasing field of development and application.

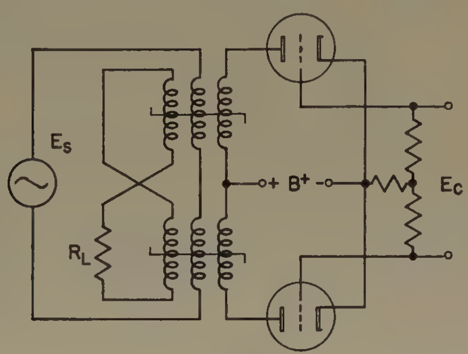


Fig. 7—A combination vacuum tube-saturable reactor magnetic amplifier circuit with the output isolated from the main power source.

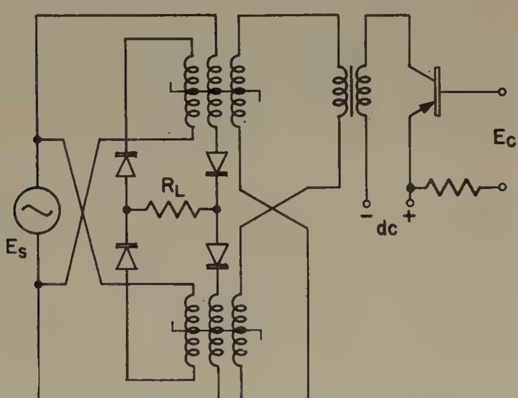


Fig. 8—A combination transistor-magnetic amplifier circuit.

The recent improvement in transistor quality and power-handling capacity have pointed the way to improved designs which in many instances appear to be better than either an all magnetic amplifier or combination transistor-magnetic amplifier system. In many of the lower power applications this may prove to be the case. For control of larger power, however, the magnetic amplifier is unmatched. Where efficiencies are obtained of the order of 50 per cent to 60 per cent with vacuum tube stages, and 60 per cent to 70 per cent with transistor stages, the magnetic amplifier will give 80 per cent to 95 per cent. Neither the transistor nor the vacuum tube at present enjoy the reputation for ruggedness, long life, and low maintenance that the magnetic amplifier has.

Theory

Circuit-wise the magnetic amplifier is a relatively simple device. This simplicity is very misleading, however, when a formal mathematical analysis of its operation is attempted. Because of the extremely nonlinear characteristics of the core materials and dry rectifiers, linear circuit theory may be applied only to carefully selected periods of its operation. For example, the control period will require one set of assumed conditions, the saturating or output period another. Effects of interwinding and rectifier capacitance, rectifier forward and reverse impedance, induced voltage and current transients, their time constants, etc. need to be carefully considered. If this is rigorously done, a complexity of terms and equations results that is extremely difficult to handle. To simplify the analysis it is common practice to make the assumptions of perfect core material and ideal rectifiers. These assumptions unfortunately do not always give resultant mathematical expressions of sufficient accuracy to predict the performance of actual practical circuits. No satisfactory general analysis of magnetic amplifier operation has yet been done although many of an approximate and specialized nature have been published.[16]

It is as yet difficult to design magnetic amplifiers on paper as one might design a vacuum tube amplifier. Thus most magnetic amplifier design today requires considerable past experience and engineering skill. It is reasonable to expect this situation to improve rapidly as more and more effort is put into this field. A survey of published papers on magnetic amplifiers indicates a very healthy increase each year.[17] In the colleges and universities little attention has been given the magnetic amplifier, per se, until very recently. At the present time a few institutions have courses dealing specifically with such circuitry.

Components

Core Materials

In order to obtain well-defined control characteristics from a magnetic amplifier it is necessary to change the saturable reactor's inductive impedance abruptly from an extremely high value to a very low value. In this way a true switching action may be closely approached. This is achieved only by careful selection and application of suitable core materials. The more rectangular the core B-H loop the better will be the switching operation obtained. It is also desirable that the core material have as low a coercive force as possible since the control action must overcome at least the coercive force (H_c) of the core before any control of flux level can be exercised. Thus the lower the H_c the less control power required. Taken together these two requirements dictate a high B/H ratio or high permeability core. Fig. 9 shows the

[15] J. J. Suozzi, " A Half-Wave Transistor Magnetic Amplifier," Master's thesis submitted to the School of Engineering and Architecture of the Catholic University of America, Washington, D. C., February 28, 1954.

[16] J. G. Miles, "Bibliography of magnetic amplifier devices and the saturable reactor art," *Trans. AIEE*, vol. 70, Part II, pp. 2104–2123; 1951.

[17] W. A. Geyger, "Magnetic Amplifier Circuits," McGraw-Hill Book Co., Inc., New York, N.Y.; pp. 6–18, 1954.

B-H loops of several core materials which, due to their rectangularity, are suitable for magnetic amplifier service. From inspection of Fig. 9, it would appear that 4–79 molypermalloy, which has very high permeability, would be the best. From the standpoint of power output, however, a high saturation flux density is also desired because for a given core volume the total volt-time integral which the core can absorb or given power source voltage it can hold back is directly proportional to the saturation flux density. Thus it is seen that the grain-oriented 50 per cent Ni-50 per cent Fe Orthonol is an excellent material having all the desirable features. For this reason a major percentage of all high-performance magnetic amplifiers built today use a core material of this type. Where very high gain is necessary a permalloy core would, of course, be used. If gain is secondary to the power to be controlled, a 4750 alloy or grain-orientated silicon iron core could be used.

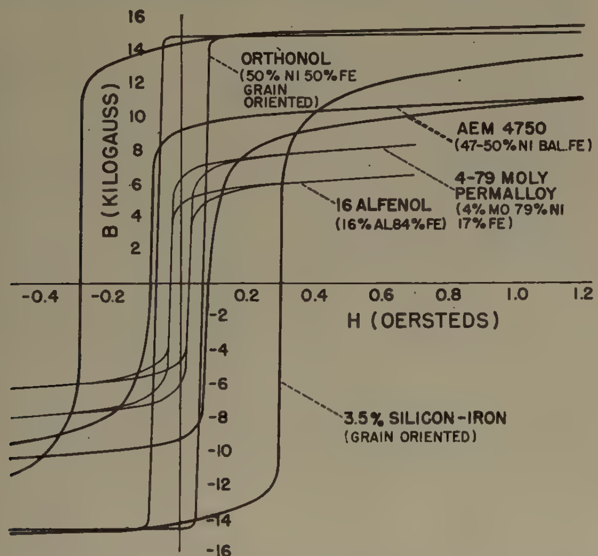


Fig. 9—*B-H* loops of typical core materials for magnetic amplifier service.

All high permeability magnetic materials are extremely strain-sensitive; therefore cores for magnetic amplifier use are usually encased in a protective box that isolates the core from any strains which might be introduced in winding and handling.

Core Types

Because the toroidal configuration has advantages over the stacked *E-I* or double-backed *U*-type core from a magnetic circuit standpoint, the toroid is to be preferred where high performance is paramount. Not only does the tape-wound toroidal core take advantage of the grain orientation of materials, such as the orientated Ni-Fe and Si-Fe, but it can be easily fabricated in very thin gauges. On the other hand a stacked core must be made from laminations carefully punched with the proper orientation if the grain-orientated materials are used. Also it cannot be assembled after anneal, if the laminations are below about 0.007 inch in thickness, without extreme precautions to avoid strain of the material. It is possible, of course, to build excellent magnetic amplifiers using a stacked laminated core, but general commercial availability of a large variety of high-grade toroidal cores (Fig. 10 below) coupled with improved toroidal winding equipment and facilities brought about a definite trend to the toroid reactor, especially in the lower power magnetic amplifier field.


Fig. 10—High permeability toroidal cores for magnetic amplifier use. The cores are encased in protective covers to avoid loss of permeability due to strain which might occur during winding and handling. (Courtesy Magnetics, Inc.)

For very large reactors, where large amounts of power are to be handled, stacked laminations of the poorer grades of core materials such as Si-Fe are frequently used. First the cost of a large core of high quality material becomes excessive and secondly the poorer gain and response characteristics which results are usually secondary to power handling capacity in such applications.

Rectifiers

Dry-disc-type rectifiers are conventionally used in magnetic amplifiers for decoupling the power windings from the control circuits, for producing dc bias, for conversion of ac to dc in the output, etc. Their use is dictated by their long life and ruggedness, their ability to handle large currents, and their relatively high efficiency. For general application it can safely be stated that the best rectifier for magnetic amplifier usage would be one having infinite back impedance and zero forward impedance. If this statement should at first sound facetious, it is pointed out that some circuits are designed to take advantage of commercial rectifier deficiencies and direct substitution of an ideal rectifier in such a circuit would result in a definite loss of operating characteristics. However, as a result of dry rectifier back leakage or forward impedance or both, it is generally necessary to reach a compomise circuit design. The decision as to whether back leakage will be sacrificed for lower forward resistance or vice versa depends upon the circuit's intended application. It is evident, referring again to the simple circuit of Fig. 1, that back leakage in the power circuit rectifiers will appear not only as a decrease in reflected impedance to the control circuit but also as an additional control action on the reactor. Hence it is most important that this leakage either be carefully controlled or kept to an absolute minimum.

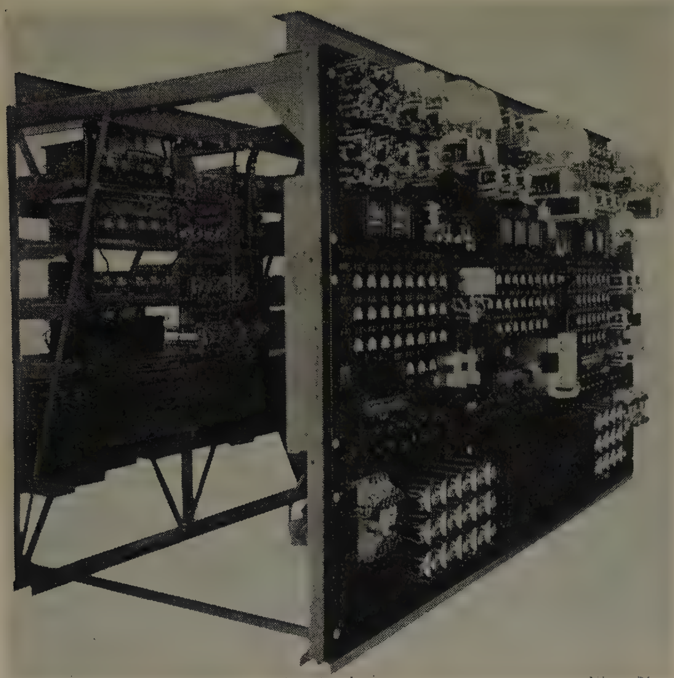


Fig. 11—Magnetic amplifier equipped control panel for a 48-inch four-high metal foil mill. A magnetic amplifier in combination with an amplidyne generator excites and controls the 800 kw main mill generator. A 4.7 KVA magnetic amplifier is used as a regulating exciter for the 1,000 hp mill motor field. The wind-up reel motors—100 hp unwind and 200 hp wind-up—employ 4.7 KVA magnetic amplifiers as field regulators. Magnetic preamplifiers regulate each of the reel motor amplidyne generators. The power section of one 4.7 KVA magnetic amplifier is shown on the lower rear rack. (Courtesy Gen. Elec. Co.)

Unfortunately dry rectifiers tend to change their characteristics with temperature and age. Thus many of the limitations of stability of the magnetic amplifier are centered in the rectifier elements. This is particularly true with respect to temperature drift. Nevertheless, by careful matching and aging of commercial quality rectifiers, their effect on the over-all amplifier can be controlled to the point where very low drift and stable systems are practical. Recent advances in the development of semi-conductor-type rectifiers offer promise of considerable improvement in this respect.

Applications

When one considers that a few years ago the magnetic amplifier was practically unknown, its widespread usage today can truly be described as phenomenal. Few people realize to what extent this device has become a part of the control, regulation and instrumentation fields. Despite the fact that it is fundamentally a device to control the impedance in an ac circuit and is primarily limited to this function alone, its potential applications have just begun to be realized. The examples given here represent but a selected few of the uses to which magnetic amplifiers have been placed. They will, however, indicate the flexibility and range of services in which it may be used.

The magnetic amplifier is one of the most efficient and reliable methods of controlling large amounts of power which we have today. In effect a properly designed unit will behave very much like a controlled switch having no moving parts and no contacts, yet requiring relatively small signals to actuate. As a result of its proven reliability and efficiency it has become one of the standard controllers for large power installations. For example, in the electric utilities industry the requirements for continuity of service are so severe that no compromise can be made on the reliability of the main generating equipment. For this reason the regulation of these systems was one of the first big industrial applications of the magnetic amplifier. The acceptance of the magnetic amplifier was accomplished with a very short "proving in" period, and today practically all generating equipment built is equipped with magnetic amplifier voltage and frequency regulators.[18,19] Indeed many systems use magnetic amplifiers all the way from the low-level voltage and frequency sensing stages through to the main generator field excitors, having replaced the conventionally used rotary amplifiers and dc exciter generators normally used.

Fig. 12—A newspaper press driven by several dc motors powered from a magnetic amplifier-controlled 300 kw power rectifier. Magnetic amplifiers are also used to supply and regulate the press motor fields. (Courtesy Gen. Elec. Co.)

The control of speed and tension in steel rolling mills, the rolling and unrolling rates, and tension of steel sheet in cleaning and pickling lines; as paper and textile mill speed regulators; as voltage and current regulators in dc supplies for arc welding; as power controllers for draw bridges, ship steering, gun turret drives, etc., are examples of but a few of the in-service applications of magnetic amplifiers in the heavy-duty control field today (see Figs. 11, 12, 13). Most of the power controlled in such heavy-duty applications is dc; hence self-saturating full-wave circuitry is commonly applied. In this way ac is converted to dc power in the same rectifiers used with the reactors to obtain high gain in the amplifier.

[18] H. F. Storm, "Voltage regulator with magnetic amplifiers for large alternators," *Proc. NEC*, vol. 7, pp. 247–253; October, 1951.

[19] E. L. Harder, "Power control with magnetic amplifiers," *Electronics*, vol. 25, pp. 115–117; October, 1952.

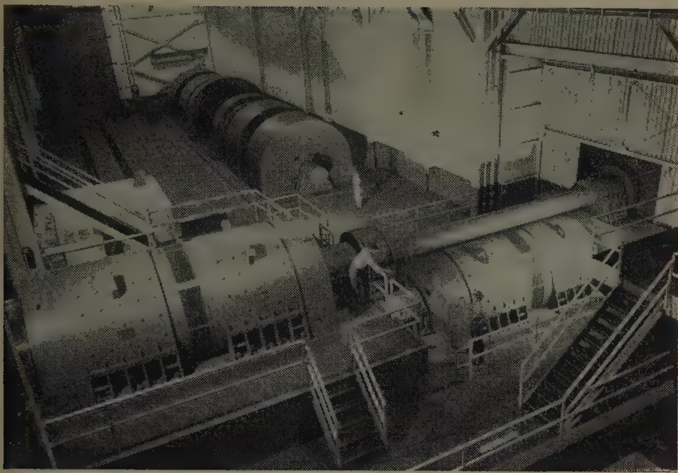


Fig. 13—A 12,000 hp blooming mill drive (with M/G set in background) which uses a magnetic amplifier to amplify current limit signals. The magnetic amplifier, in combination with amplidyne regulators on the motor and generator fields, permits rapid reversals of one second at base motor speed and 2½ seconds at top motor speed. (Courtesy Gen. Elec. Co.)

The magnetic amplifier is by no means limited to the field of heavy equipment. In the regulation of low power generators excellent performance has been obtained (see Fig. 14). In the small instrument-type servo field, great strides have been made until today, within its limitations of input impedance and bandwidths (due to the inherent time delays previously discussed), dynamic performance equal to that produced with vacuum tube amplifiers is not uncommon.[20] For example, with a 60-cycle ac supply source bandwidths of from 6 to 10 cycles may be achieved, while with a 400-cycle supply 15- to 20-cycle bandwidths are possible.

Recent advances in applying conventional servo compensation techniques to magnetic amplifiers make possible design of systems incorporating lead, lag, lead-lag, integral and lead-integral compensation within the amplifier itself.[21] Using these techniques in servo controllers it is now possible to replace high-performance vacuum tube controllers in many precision servos that but a few years ago were considered completely out of the range of the magnetic amplifier. The potentials of its applications in this field are indeed far-reaching. The complexity of many of our present-day control systems has become so great and continuity of service so important that failure in any component can scarcely be tolerated. Magnetic servo controllers give the reliability required. They are thus becoming standard servo controller equipment in the guided missile field, in aircraft, submarines, and on shipboard (see Figs. 15, 16, 17, 18 on the following page).

Because of certain of its inherent properties the magnetic amplifier is ideally suited for many instrumentation applications. For example, the saturable-reactor-type circuit possesses current transformer characteristics in that control dc ampere turns are reproduced as average output ampere turns. Thus by using a single-turn control winding carrying large dc currents with a multi-turn low-level ac power winding it is possible to match huge control current ampere turns with small power circuit current ampere turns in a completely isolated circuit.[22] Their use, therefore, in metering large dc currents—as, for example, in big electroplating installations, electro-processing of aluminum, etc.—is evident. Input levels as low as 10^{-12} watts are capable of controlling magnetic amplifiers. Consequently for thermocouple inputs and the like they are well-suited as metering amplifiers. With compound feedback circuitry it is possible to build magnetic amplifiers which behave as voltmeters having extremely high impedance or ammeters having extremely low impedance.[14] Use of magnetic amplifiers as tubeless audio amplifiers has been shown to be practical[23] although the lack of suitable high frequency power sources to obtain the necessary bandwidth is a definite drawback to their use in such service.

In many special applications magnetic amplifier circuitry is being applied to perform operations which are not primarily of amplification. Perhaps the most outstanding example is the bi-stable magnetic decision element[24] which has become a powerful tool in the design and construction of digital computer systems. The ease with which multiple inputs may be mixed in a single reactor makes their use in analog computers ideal.[25]

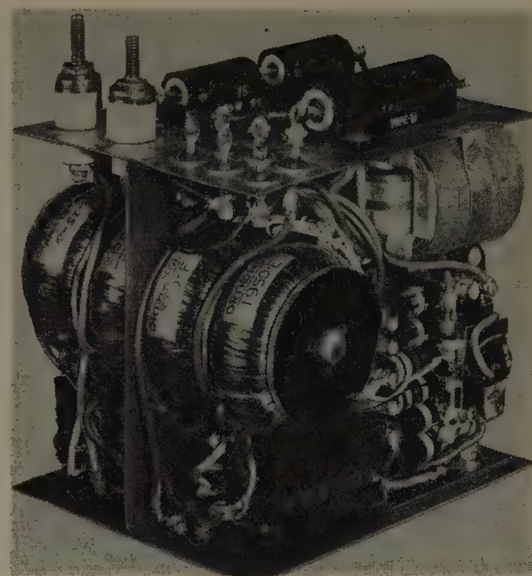


Fig. 14—A magnetic amplifier voltage and frequency regulator for a 750 volt-ampere inverter for use in a guided missile. Regulation of 2 per cent on voltage and 1 per cent on frequency is obtained over extreme conditions of temperature, input voltage and load. (Official U. S. Navy Photo.)

[20] C. W. Lufcy, A. E. Schmid, and P. W. Barnhart, *op. cit.*, p. 110.

[21] H. H. Woodson, C. V. Thrower, and A. E. Schmid, "Compensation of a magnetic amplifier servo system," *Proc. NEC*, vol. 8, pp. 158–165; 1952.

[22] W. F. Horton, "Isolation metering of d-c bus currents," *Proc. NEC*, vol. 7, pp. 260–262; October, 1951.

[23] J. J. Suozzi and E. T. Hooper, *op. cit.*

[24] A. Wang, "Magnetic delay-line storage," Proc. I.R.E., vol. 39, pp. 401–407; April, 1951; also R. A. Ramey, "The single core magnetic amplifier as a computer element," *Trans. AIEE*, vol. 71, part I, pp. 442–446; 1952.

[25] B. E. Davis and I. H. Swift, "An analog computer technique using magnetic amplifiers," *Trans. AIEE*. Paper 54–389, presented at Fall General Meeting, Chicago, Ill., October 11-15, 1954.

Fig. 15—A packaged high performance magnetic amplifier servo controller for airborne applications. This amplifier, which will control a 5-watt ac motor, is completely self-contained. (Courtesy Specialties, Inc.)

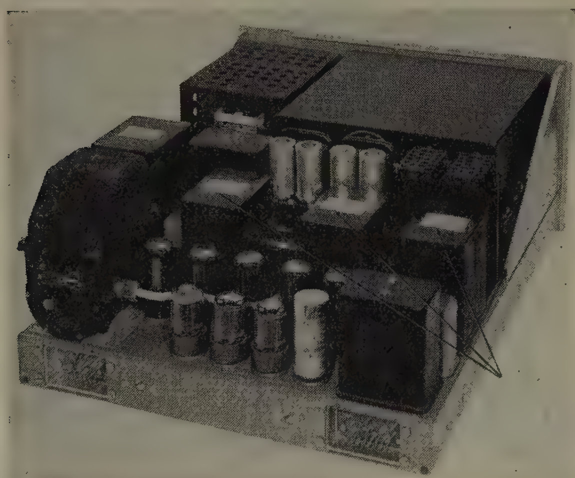


Fig. 16—A commercial auto-pilot three-channel servo controller with combination vacuum tube input-magnetic amplifier output. Arrows point out the three magnetic amplifier output stages. (Courtesy Eclipse-Pioneer Div., Bendix Aviation Corp.)

With sufficient positive feedback an ordinary magnetic amplifier can be made unstable to the point where a small additional control current will result in its going from zero output to full output or vice versa, thus performing the operations of a relay without moving parts or contacts.[26]

Current Status

Rapid as the growth of the magnetic amplifier field has been, it is still retarded by a lack of engineers trained in the design and utilization of such circuitry. A major portion of the potential applications is in the field of servomechanisms, which is in itself a highly specialized field. Generally the servo engineer has a background in electronics and electron tube design but little or no experience with magnetic circuitry. As a result many applications which could be handled with magnetic amplifiers are instead solved by other methods, for, without some knowledge of the magnetic amplifier's characteristics, it is difficult to specify or balance their capabilities against known requirements. Other

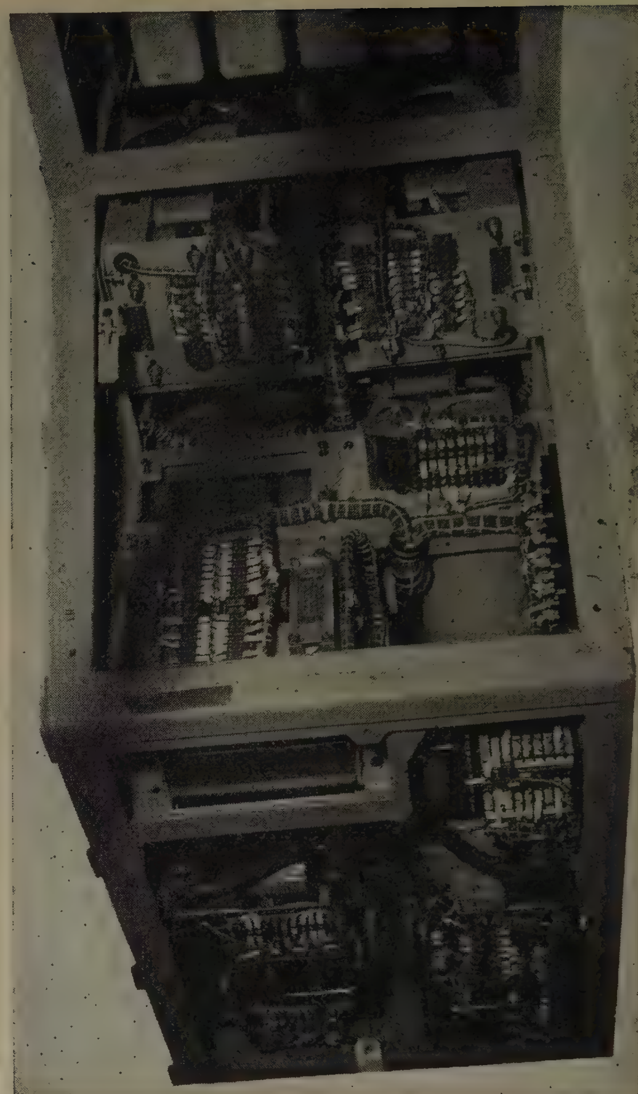


Fig. 17—A cubicle containing several magnetic servo amplifiers used in control of a submarine atomic power plant. These units were designed for long life, very high degree of reliability, and ability to withstand high shock and vibration. (Courtesy Gen. Elec. Co.)

Fig. 18—A three-channel magnetic amplifier servo controller for a small search-track antenna system. One channel controls azimuth, the second controls elevation, and the third controls switching to govern the search pattern. (Courtesy Gen. Elec. Co.)

[26] A. U. Lamm, "The Transductor, D-C Pre-Saturated Reactor, with Special Reference to Transductor Control of Rectifiers," ("Transductor Locking Relay") 2nd. ed., pp. 19–20, Esselte Aktiebolag, Stockholm, Sweden; 1948.

practical considerations, such as available production facilities and engineering costs, also frequently exclude their use. These factors, however, will become less important as more engineering know-how and production experience are gained. The relative simplicity of the magnetic amplifier makes for easier, cheaper and faster assembly once a system has been properly designed and engineered.

The magnetic amplifier is no longer a laboratory device but has been tested and proven in actual military and industrial service until today it is a major factor in the design and development of an ever-increasing number of new and improved systems.

Reliability is by no means the only virtue of the magnetic amplifier. In many applications it has proven to be superior in performance, size and cost to vacuum tube amplifiers, rotary amplifiers and even mechanical devices. No other amplifier offers such a combination of long life; low maintenance; ruggedness; resistance to extreme conditions of vibration, shock and temperature; no warm-up time; and high efficiency, in a completely static device which may be permanently sealed or potted. The day of the magnetic amplifier has arrived.

Acknowledgment

The author gratefully acknowledges the assistance of the many people in the magnetic amplifier field who so freely gave their time and advice in the initial preparation of this paper. Special thanks are given to E. T. Hooper and W. A. Geyger of the Naval Ordnance Laboratory for assistance in the final preparation of the manuscript.

The "M"-Type Carcinotron Tube*

R. R. WARNECKE†, FELLOW, IRE, P. GUÉNARD†, SENIOR MEMBER, IRE, O. DOEHLER†, AND B. EPSZTEIN†

Summary—This paper presents theoretical and experimental results concerning the "M Carcinotron." In particular, the influence of space charge has been considered, thereby permitting an explanation for the measured values of starting current, the influence of the coupling impedance on efficiency and the existence of parasitic oscillations. The "rising sun effect" which should be present in these tubes, as it is in the magnetron, has been investigated theoretically and experimentally. The experimental results exhibit a decrease of efficiency in the predicted range of operation.

Introduction

THE Carcinotron[1] tubes are backward-wave oscillators. Their structure is characterized by the following features:

1. An electron beam is in interaction with a backward space harmonic of a delay line.
2. The power output is located at the gun end of the interaction space.
3. Means for absorbing rf energy reflected by possible output mismatch are introduced in the rf field of the delay line near the collector end generally inside the tube.

This structure gives a very wide electronic tuning range, and frequency insensitivity to load impedance.

Two types of Carcinotron tubes have been investigated: the "O" type, in which the beam travels in an interaction space at constant dc potential, as in the classical traveling-wave tube, and the "M" type, where the beam travels perpendicularly to crossed electric and magnetic fields, as in the magnetron amplifier.

This paper deals with the "M" Carcinotron. The structure of this tube and the results of a simplified small signal theory were given in a short note published in 1952.[2] The methods used to obtain these results were more fully described later.[3,4]

The aim of this paper is to describe with more detail the properties of the "M" type Carcinotron, gathering and completing the information given previously.[5-7]

A small signal theory taking into account space-charge effects is established, allowing expressions for the starting current and frequency, build-up time and frequency pulling to be derived. The results of this theory are checked against experimental data. Some effects typical of the "M" Carcinotron (rising sun effect, parasitic oscillations) are explained. The practical interest of the "M" Carcinotron is best shown by the per-

* Original manuscript received by the IRE, November 9, 1954; revised manuscript received December 16, 1954.

† Electronics Dept., Center of Tech. Res., Compagnie Générale de Télégraphie sans fil, Paris, France.

[1] Registered trade-mark of the Compagnie Générale de T.S.F.

[2] P. Guénard, O. Doehler, B. Epsztein, and R. Warnecke, "Nouveaux tubes oscillateurs à large bande d'accord électronique pour hyperfréquences," *C. R. Acad. Sci.* (Paris), vol. 235, pp. 235–236; July, 1952. They were given previously, together with experimental results, by Epsztein at the 10th Conference on Electron Tube Research, Ottawa, Can., June 1952, in a discussion on R. Kompfner's paper "Backward waves," presented at this conference.

[3] R. Warnecke and P. Guénard, "Some recent work in France on new types of valves for highest radio-frequencies," *Proc. IEE*, vol. 100, part III, p. 351; November, 1953.

[4] R. Warnecke, P. Guénard, and O. Doehler, "Phénomènes fondamentaux dans les tubes à onde progressive," *L'Onde Electrique*, no. 325; April, 1954.

[5] P. Guénard, R. Warnecke, O. Doehler, and B. Epsztein, "A new wide electronic tuning high efficiency microwave oscillator, the M Carcinotron," paper presented at the 11th Conference on Electron Tube Research, Stanford University, Stanford, Calif., June 1953.

[6] P. Guénard, "On some results obtained with O and M type Carcinotron," paper presented at the 12th Conference on Electron Tube Research, University of Maine, Orono, Me., June, 1954.

[7] O. Doehler, "Space charge effects in traveling wave tubes using crossed E-H fields," paper presented at the Symposium on Modern Advances in Microwave Techniques, New York, N. Y., October, 1954.

formances obtained on this type of tube, some of which are given at the end of the paper. These performances, together with those previously published,[3,4,8] suggest that the "M" Carcinotron should be best suitable when high power high efficiency operation is required.

Description of the "M" Carcinotron

Fig. 1 shows a linear version of the "M" Carcinotron. A delay line L is perfectly matched at the end M near the collector K by means of an attenuating material to avoid reflections. N is the output. An electron beam F, produced by the gun, travels parallel to the delay line L, and the sole S in the x-direction under the influence of a constant and uniform magnetic field B in the z-direction and an electric field E_0 in the y-direction due to the voltage V_0 applied between L and S.

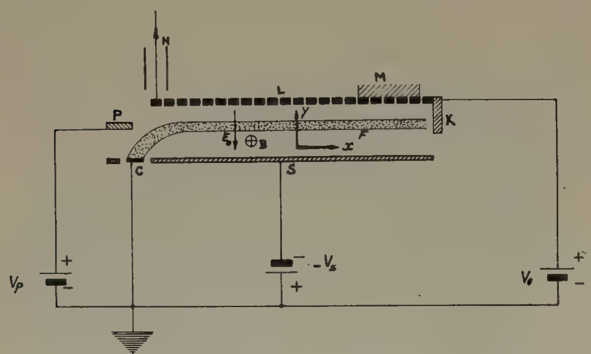


Fig. 1—Schematic structure of a linear "M" Carcinotron.

Interaction between the beam and the backward space harmonic will occur, if the phase velocity of the space harmonic is equal or nearly equal to the mean electron velocity $v_e = E_0/B$, i.e.:

$$v \cong v_e = E_0/B. \qquad (1)$$

The positive feedback introduced by the beam leads to an oscillation if the current is high enough. This oscillation occurs with perfect matching at both ends of the line, the necessary feedback being furnished by the beam only. The oscillation frequency will be that for which (1) is fulfilled.

The beam focusing and the transfer of energy from the beam to the rf field occur in the same manner as in the magnetron amplifier:[9] the transverse rf field produces a beam bunching in the favorable phase of the longitudinal rf electric field.

The energy transfer from the beam to the electromagnetic field of the line is achieved through the longitudinal electric field. The electrons which transfer energy to the rf field, approach the anode and are brought to a higher dc potential, their velocity remaining approximately constant and equal to E_0/B.

As compared to the mechanism of operation of the "O" Carcinotron, it can be said that in the traveling-wave tubes with crossed electric and magnetic fields the potential energy of the electrons is transformed into rf energy; while in the "O" type traveling-wave tubes the kinetic energy of the electrons is transformed into rf energy.

Small Signal Theory

Small Signal Theory Neglecting Space Charge

In this theory, a rectilinear beam is considered. In the equations of the static trajectories

$$x = v_e\tau + a \cos (\omega_r\tau + \phi)$$
$$y = y_0 + a \sin (\omega_r\tau + \phi),$$

where τ is the transit time and $\omega_r = eB/m$, the cyclotron angular frequency, the amplitude a of the rolling circle is assumed zero, a condition which can be obtained with a proper set of initial conditions. Assuming that all rf quantities vary as $\epsilon^{\delta(\omega t - \Gamma x)}$, there exist, in the absence of coupling between the beam and the line, six waves

Beam	$\Gamma_1 = \Gamma_5 = \Gamma_e = \dfrac{\omega}{v_e}$	δx and δy arbitrary $\delta\dot{x} = 0, \ \delta\dot{y} = 0$
	$\Gamma_{3,4} = \dfrac{\omega \pm \omega_r}{v_e}$	$\delta y = \mp j\delta x$ $\delta\dot{x} = \mp j\omega_r\delta x, \ \delta\dot{y} = \mp j\omega_r\delta y$
Line	$\Gamma_2 = \Gamma_0$	$E_y = jKE_x$
	$\Gamma_6 = -\Gamma_0$	$E_y = -jKE_x,$

where δz, δy, $\delta\dot{x}$, $\delta\dot{y}$ are the rf components of electron motion, E_x and E_y the field components in the beam, and $K = \coth \Gamma y_0$.

The coupling between the beam and the line can modify significantly only those waves for which the propagation factors are near one another, i.e. the two beam waves Γ_1, Γ_5 and the line wave Γ_2.

This assumes that one space harmonic only is considered. There is a possibility of simultaneous coupling of beam waves with different space harmonics, a question which will be discussed later (rising sun effect).

The theory (Appendix A) shows that one of the beam waves, say Γ_5, is not coupled to the line. For this wave:

$$\Gamma_5 = \Gamma_e \qquad \delta x = jK\delta y \qquad \delta\dot{x} = \delta\dot{y} = 0 \qquad E_x = E_y = 0.$$

The modified values of Γ_1 and Γ_2 are solutions of the equation:

$$(\Gamma - \Gamma_e)(\Gamma - \Gamma_0) = \frac{\Gamma_0^2\Gamma_e R_c I_0 K}{E_0} = \gamma_M^2, \qquad (2)$$

where R_c is the coupling impedance, I_0 and E_0 the dc beam current and electric field. The two solutions can

[8] R. Warnecke, "Sur quelques résultats récemment obtenus dans le domaine des tubes pour hyperfréquences," *Ann. Radioélect.*, vol. ix, pp. 107–135; April, 1954.

[9] R. Warnecke, W. Kleen, A. Lerbs, O. Doehler, and H. Huber, "The magnetron type traveling-wave amplifier tube," Proc. I.R.E., vol. 38, pp. 486–495; May, 1950. See also J. R. Pierce, "Traveling-wave Tubes," D. Van Nostrand Co., Inc., New York, N. Y., chap. XV; 1950.

be written:

$$\Gamma_{1,2} = \Gamma_m \pm \sqrt{\Gamma_d^2 + \gamma_M^2},$$

where

$$\Gamma_m = \frac{\Gamma_0 + \Gamma_e}{2}$$

$$F_d = \frac{\Gamma_e - \Gamma_0}{2}.$$

For these waves:

$$\delta x = \frac{K}{\Gamma - \Gamma_e} \frac{E_x}{E_0}, \quad \delta y = j\frac{\delta x}{K}, \quad \delta \dot{x} = -j(\Gamma - \Gamma_e)v_e \delta x, \quad \delta \dot{y} = j\frac{\delta \dot{x}}{K}.$$

The three other waves are only slightly modified by the coupling.

This theory can be extended to a beam of finite thickness if the trajectories are linear, which means that a nonequipotential cathode is used. It is then found that the rf charge density inside the beam is zero (see Appendix A).

In addition to assumptions already mentioned, it has been supposed that the periodicity of the line structure has no influence on the static trajectories, i.e. that the distance between the line and the sole is large as compared to the pitch of the line. A two-dimensional problem has been treated, which supposes the structure infinite in the z direction.

These six waves make it possible to satisfy the boundary conditions, i.e. the values of δx, δy, $\delta \dot{x}$, $\delta \dot{y}$ at $x=0$ (gun end of the line) and the existence of reflection factors a_0 and a_l at the ends of the line. If it is supposed that $\delta x = \delta y = \delta \dot{x} = \delta \dot{y} = 0$ for $x=0$, the amplitudes of the waves Γ_3, Γ_4, Γ_5 are found equal to zero and there remain only the two principal waves Γ_1, Γ_2 and the reflected wave Γ_6.

Small Signal Theory Taking Into Account Space Charge

It is no more possible in this case to consider an infinitely thin beam. As shown by Brillouin,[10] linear trajectories are possible, assuming an equipotential cathode, if the plasma frequency Ω_0 equals the cyclotron frequency ω_r:

$$\Omega_0 = \sqrt{\frac{e}{m}\frac{\rho_0}{\epsilon_0}} = \frac{eB}{m} = \omega_r,$$

ρ_0 being the charge density in the electron beam. The electron velocity varies inside the beam as $\omega_r y$.

If a nonequipotential cathode is used, it is possible to avoid this condition; with a constant charge density in the beam, the electron velocity varies as $y\Omega_0^2/\omega$.

It has been supposed, with no other basis than the agreement between theory and experimental data, that it is possible to apply the results thus obtained to a beam with complicated trajectories, if the charge density in the linear beam is taken equal to the average charge density in the actual beam.

The general space-charge theory leads to a transcendental equation which is difficult to solve. Therefore, the influence of space charge has been introduced as a perturbation in the theory without space charge in the following manner:[11] The beam travels in an rf field which is the sum of the field Φ_L guided by the line and the field Φ_c created by the space charge. The trajectories of the electrons are determined by $\Phi_L + \Phi_c$, while the transfer of energy from the beam to the line is determined by Φ_L only. The approximation consists in calculating Φ_c from trajectories determined without space charge. This leads (see Appendix A) to the following values of the propagation constants for the two principal waves:

$$T_{1,2} = \Gamma_m \pm \sqrt{\Gamma_d^2 + \gamma_M^2\left(1 - \frac{\alpha}{\Gamma_d \mp \sqrt{\Gamma_d^2 + \gamma_M^2}}\right)}, \qquad (3)$$

where

$$\alpha = \frac{\Omega_0^2 \Gamma \Delta}{\omega v_e}.$$

2Δ is the width of the beam.

Starting Conditions

The boundary conditions give the starting conditions for oscillations[4]

$$(\Gamma_2 - \Gamma_e)(a_0 a_l \epsilon^{j\Gamma_0 l} - \epsilon^{-j\Gamma_2 l}) = (\Gamma_1 - \Gamma_e)(a_0 a_l \epsilon^{j\Gamma_0 l} - \epsilon^{-j\Gamma_1 l}). \qquad (4)$$

If the line is matched at least at one end ($a_0 a_l = 0$) and if it has no attenuation, the starting conditions are:

$$v_0 = v_e \qquad (5)$$

$$\gamma_M l = \frac{\pi}{2} + 2\pi n \quad (n = 0, 1, 2 \cdots) \qquad (6)$$

Eq. (5) says that for every possible oscillation ($n=0$, 1, etc.) the phase velocity of the line at the oscillating frequency is equal to the electron velocity. Eq. (6) is the condition for the starting current.[2]

$$I_s = \left(\frac{\pi}{2} + 2\pi n\right)^2 \frac{E_0}{\Gamma_0^2 \Gamma_e l^2 R_c} \operatorname{tangh} \Gamma y_0, \qquad (7)$$

l being the length of the line. The influence of an attenuated line and of reflections already have been discussed.[4] If space charge effects are taken into account, (3) must be used, and the starting conditions are:

$$\Gamma_d = \frac{\alpha}{2} \qquad (8)$$

[10] L. Brillouin, "Trajectories in a single anode magnetron," *Elec. Commun.*, p. 460; 1946.

[11] R. Warnecke, O. Doehler and O. Bobot, "Les effets de la charge d'espace dans les tubes à propagation d'onde à champ magnétique," *Ann. Radioélect.*, vol. V, p. 279; October, 1950.

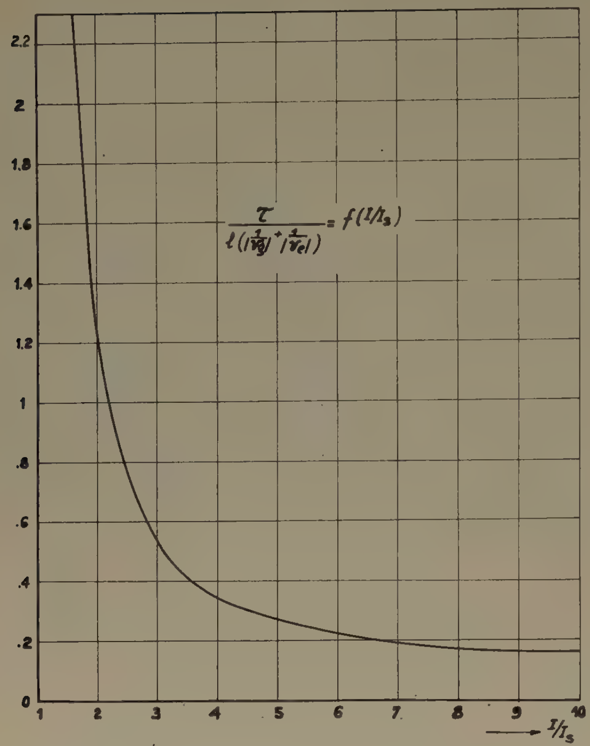


Fig. 2—Build-up time as a function of beam current.

$$\gamma_M l\left(1+\frac{3\alpha^2}{8\gamma_M{}^2}\right)=\frac{\pi}{2}+2\pi n. \qquad (9)$$

Eq. (8) shows that, in the presence of space charge, the phase velocity of the line at the oscillating frequency is not the same as the electron velocity and assumes different values for the various values of n.

Eq. (9) shows that the starting current is decreased by the effect of space charge.

Build-Up Time

If the beam current is higher than the starting current, the tube oscillates and the rf amplitude starts increasing with t, the time dependent factor being:

$$\epsilon^{j\bar{\omega}t} = \alpha^{j\omega t + t/\tau}.$$

The time τ characterizes the build-up time for small values of t and permits the determination of the approximate order of magnitude of the build-up-time.

The calculation of τ is analogous to the calculation of the starting current. But the balance of power must be modified to take into account the increase of the amplitude.

The power transferred by the beam to the rf field in a section dx of the line, and during the time dt, is the sum of:

1. The energy absorbed by the line in the length dx and during the time dt.
2. The increase of power, propagated along the line in the section dx and during the time dt.

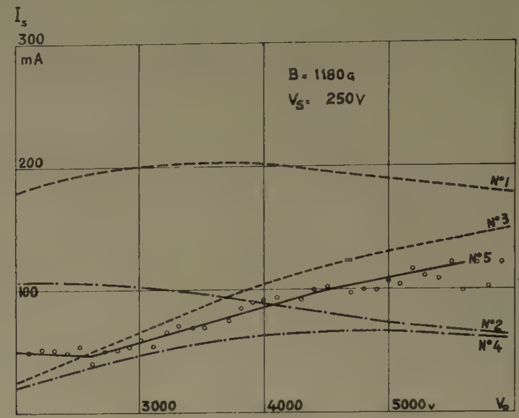


Fig. 3—Starting current as function of voltage. (1) Without space charge—linear trajectories. (2) Without space charge—cycloidal trajectories. (3) With space charge—linear trajectories. (4) With space charge—cycloidal trajectories. (5) Experimental curve.

3. The increase of electromagnetic energy dW stored in the section dx during the time dt.

$$dW = j(\bar{\omega} - \omega_0)W\,dx\,dt$$

W = stored energy per unit length,
ω_0 = angular frequency of the free wave.

If space charge is neglected, the equation which determines the propagation constant then has the form:

$$\Gamma - \Gamma_e - \frac{\bar{\omega}-\omega_0}{v_g} = \frac{\gamma_M{}^2}{\Gamma - \dfrac{\bar{\omega}}{v_e}}. \qquad (10)$$

v_g is the group velocity.

The boundary conditions of rf current for $x=0$ and of electric field for $x=l$ permit determination of $\bar{\omega}$.

If there is a perfect match at least at one end of the tube and if the line has no attenuation, ω and τ are given by:

$$\omega = \omega_0 \qquad (11)$$

$$\cos\left[2\gamma_M l\sqrt{1-\left(\frac{\theta}{2\gamma_M}\right)^2}\right] = -\left[1-2\left(\frac{\theta}{2\gamma_M}\right)^2\right] \qquad (12)$$

with:

$$\theta = \frac{1}{\tau}\left[\frac{1}{|v_g|}+\frac{1}{|v_e|}\right]. \qquad (13)$$

Eq. (12) is a transcendental equation for θ, if γ_M, i.e. the current, is given. In Fig. 2,

$$\frac{\tau}{l\left(\dfrac{1}{|v_g|}+\dfrac{1}{|v_e|}\right)}$$

has been plotted as a function of I/I_s (I_s = starting cur-

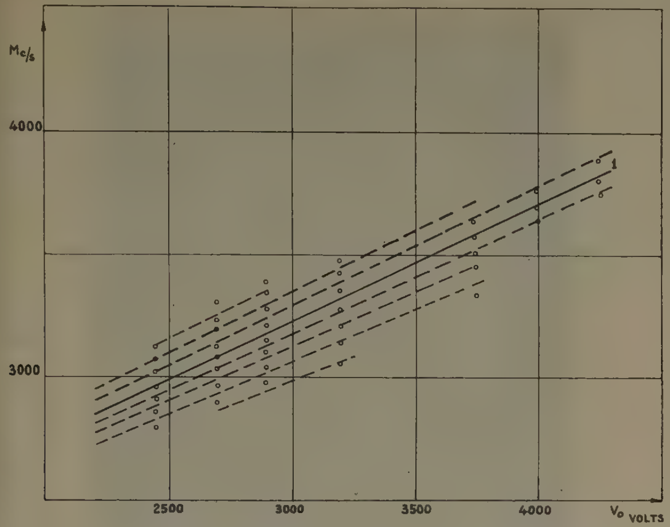


Fig. 4—Frequency of parasitic oscillations as a function of voltage (solid curve-normal oscillation).

rent). If I/I_s is large, τ is given by the approximate expression:

$$\tau = \frac{1}{\pi} \frac{1}{\sqrt{I/I_s}} \cdot l \left(\frac{1}{|v_g|} + \frac{1}{|v_e|} \right).$$

In practice, τ is of the order of 10^{-9} seconds in the "*S*" band tubes. The total build-up time is then of the order of 10^{-7} to 10^{-8} seconds.

In the presence of space charge, τ decreases, so that (12) and (13) give the upper limit for τ.

Experimental Results

Starting Current

The theory for the starting current has been checked on different types of experimental tubes with a linear structure. Fig. 3 shows the results obtained with a linear tube. The starting current is a function of the shape of the trajectories, and it has been calculated for two different electron guns. For the "ideal" gun trajectories are straight lines; for the "magnetron gun trajectories are cycloids as in the plane magnetron without space charge. In practice, the trajectories are between these two limits. Curves 1 and 2 have been calculated from (6) neglecting space charge. Curves 3 and 4 have been calculated from (9). Curve 5 has been measured. The theory neglecting space charge gives starting currents much too high, especially at low voltages; the space charge has an important influence on the starting conditions and the theory gives the correct order of magnitude.

Parasitic Oscillations

For high currents and low voltages, parasitic oscillations can be observed. Sidebands with an amplitude from 1/100 to ⅓ that of the principal frequency occur.

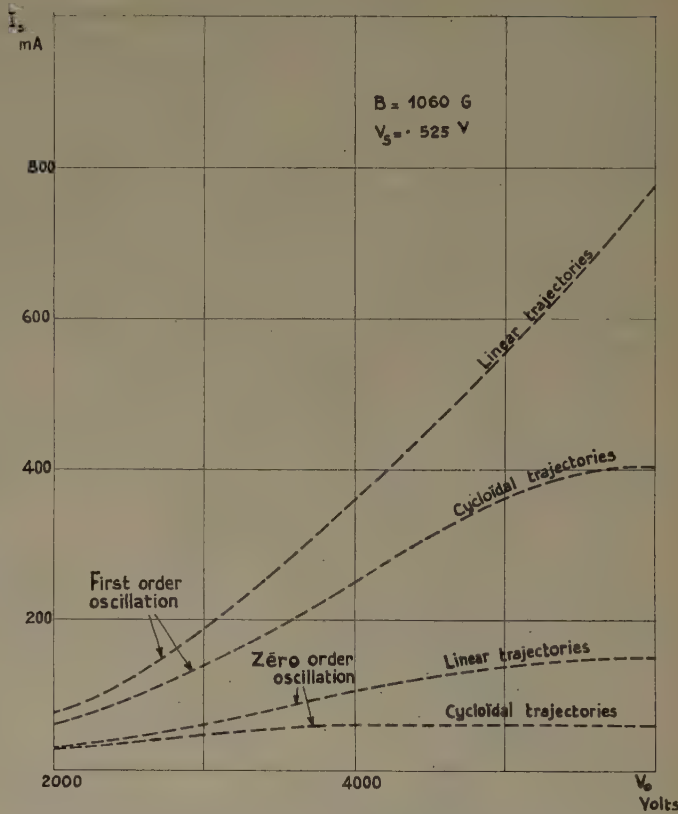


Fig. 5—Theoretical starting current for normal oscillation and first parasitic oscillation.

In Fig. 4 the main frequency and the measured sidebands as a function of voltages are shown. The difference of frequency between successive bands is approximately 60 mc. The amplitude is smaller for sidebands of higher order.

These oscillations can be attributed to the excitation of the higher orders as given by (9). In Fig. 5 the theoretical starting current of the zero order ($n=0$) and of the first order ($n=1$) have been plotted. It follows that the starting current of the first order for low voltages is only three times higher than that of the zero order. The frequency difference between these two oscillations is almost independent of voltage and, for the case of Fig. 4, has from (8) a theoretical value of 45 to 70 mc for different trajectories of the electrons.

The high frequency sidebands can be explained by intermodulation between these two oscillations, and an asymmetry must appear, as shown in Fig. 4.

Pushing Figure

If small signal theory with space charge were used to calculate the frequency as a function of current, large variations (a few per cent) of frequency should occur. But measurements show that the pushing figure is relatively low. Measurements on a tube in the "S" band have shown that variation of frequency is 2 to 3 mc for high voltages (5,000 v) and 5 mc for low voltages (2,500 v) when the power output varies from one to ten.

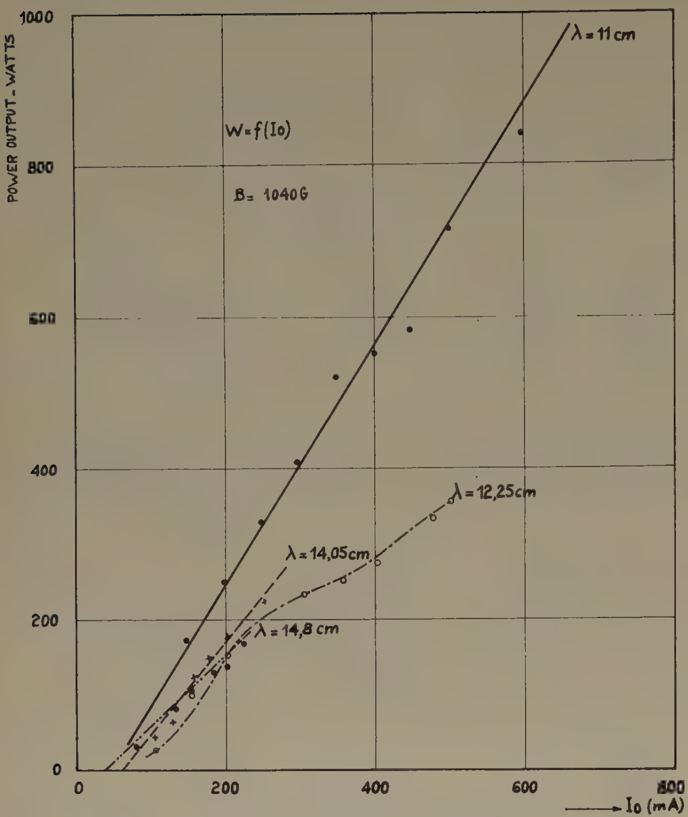


Fig. 6—Power output as function of beam current for various frequencies.

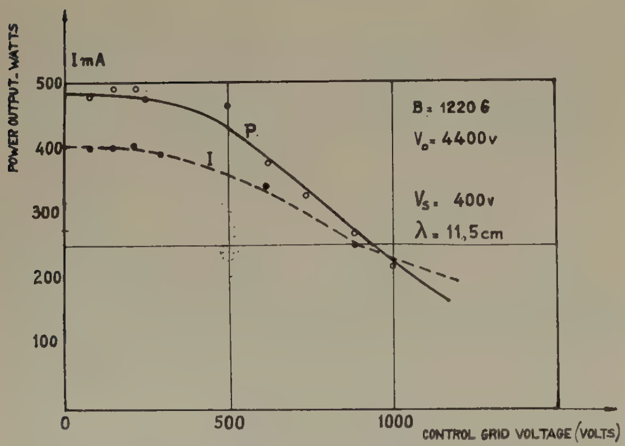


Fig. 7—Power output and beam current as functions of control grid voltage.

Fig. 8—Oscillogram of power output against control electrode voltage.

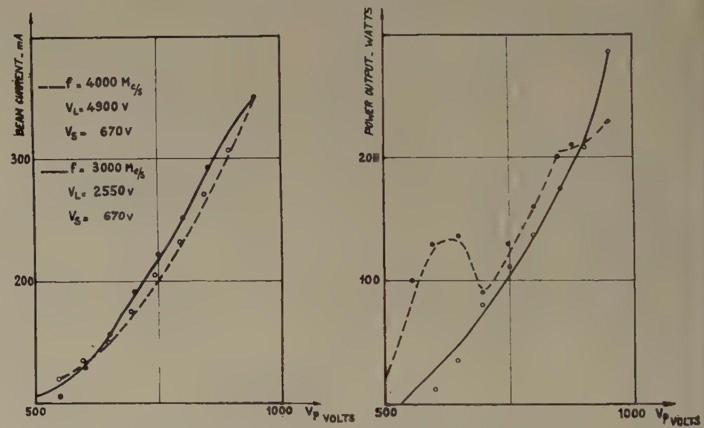


Fig. 9—Power output and beam current as a function of plate voltage.

Amplitude Modulation

In Fig. 6, power has been plotted as a function of beam current for different frequencies. For these experiments a tungsten filament was used and the current controlled by the temperature of the filament.

Usually, these curves are straight lines and power output is of the form:

$$P = A(I - I_s),$$

I_s being the starting current and A a constant.

For some frequencies, especially at low voltages, $P=f(I)$ has a more complicated form. Up to now, this has not been explained.

Fig. 7 shows rf power and beam current as a function of control grid voltage for two frequencies.

Fig. 8 shows the power output as a function of grid voltage for a 50 cps modulation.

This characteristic remains unchanged for modulating frequencies up to at least 5 mc.

The control grid is an electrode surrounding the filament. The "cutoff" is relatively high. It is also possible to control the current with the plate of the optical system. In this case the modulating voltage is lower. But as shown in Fig. 9 the power vs plate voltage curve is sometimes more complicated because the shape of the trajectories is influenced by the plate voltage.

Influence of Load

If attenuation at the end of the line near collector gives a perfect match and there is no reflection along circuit from machining irregularities, frequency will be in-

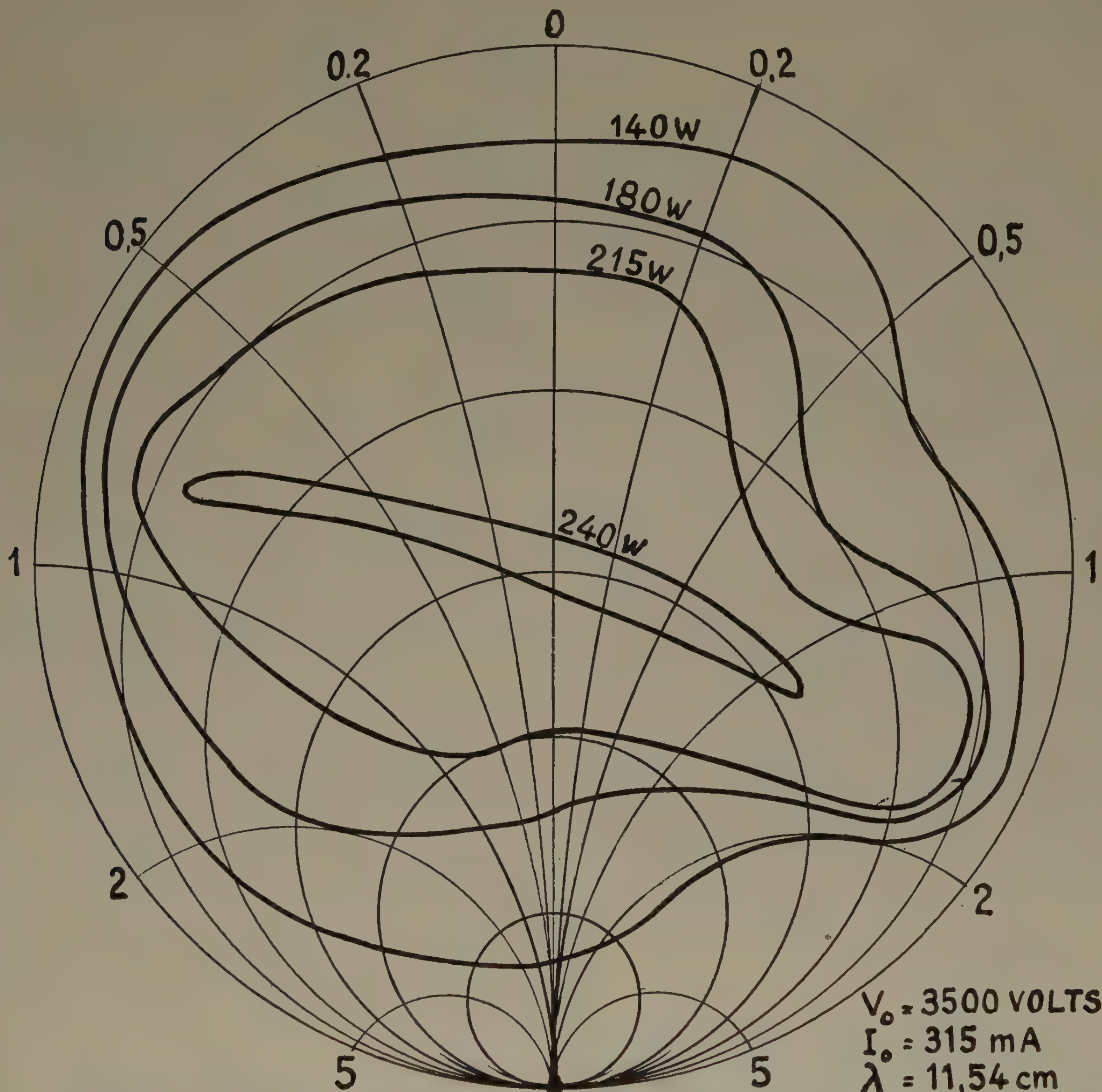


Fig. 10—Lines of constant power on a Smith chart.

dependent of load and curves of constant power must be circles about the center of the Smith chart.

Fig. 10 is the Rieke diagram for constant power. Variation of frequency was below measurement accuracy (1 mc).

Fig. 11 (next page) shows frequency vs sole-voltage for an imperfect attenuation at end of line near the collector. Parameter is vswr introduced in the output circuit. The form of the curves agrees with theory.[5]

Signal to Noise Ratio

The measurement of the signal-to-noise ratio is possible, if the "M" carcinotron itself is used as local oscillator. In this case, the variations of frequency due to the ripples in the power supplies cancel out, but it is not possible to separate the two noise sidebands. The noise of the Carcinotron was compared with a mercury-argon noise source amplified with a low-noise traveling-wave tube.

Fig. 12 (next page) shows noise per cps to signal ratio as a function of frequency distance from oscillating frequency. Noise per cps to signal ratio is of the order of −140 db.

Fig. 13 (page 421) shows the noise in relative units as a function of current.

Efficiency

Electronic Efficiency: If space charge is neglected the electronic efficiency η_e can be calculated with the same method as in the magnetron amplifier. If all electrons are absorbed by the line, η_e is given by:

$$\eta_e = 1 - m\frac{V_f}{V_0}\cdot$$

V_f is the voltage corresponding to the drift velocity of

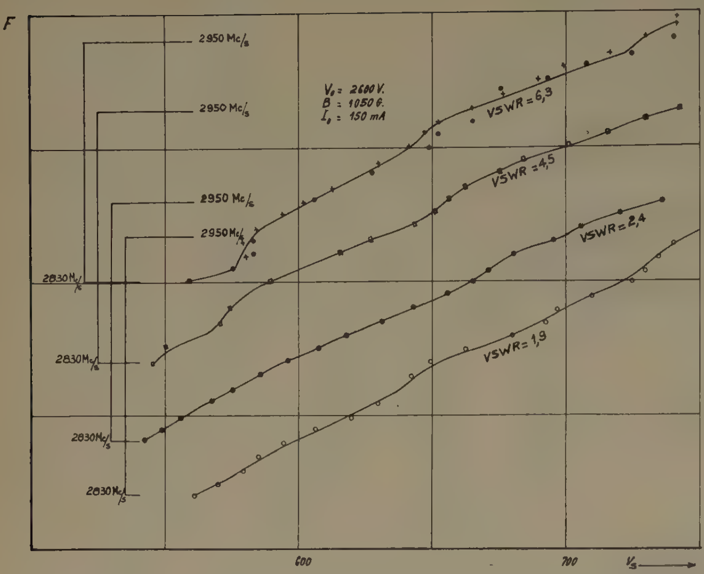


Fig. 11—Frequency vs sole voltage for various values of load vswr (ordinate curves have been translated for the various curves).

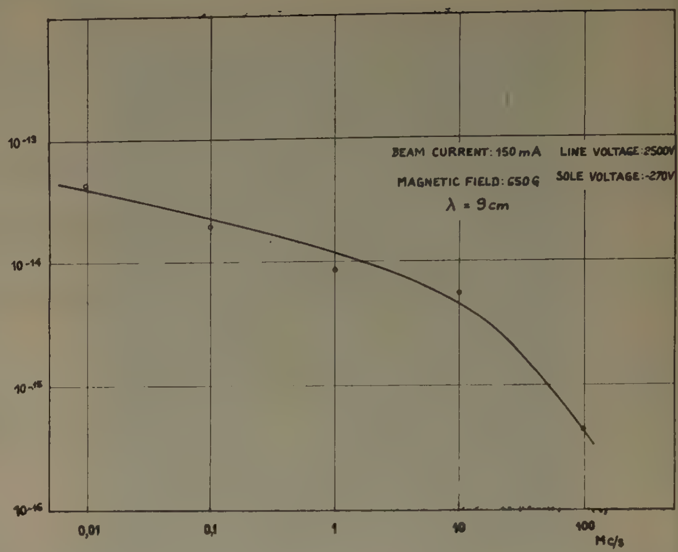


Fig. 12—Noise-to-signal ratio for a 1 cps bandwidth. The abscissa is the difference between the oscillating frequency and the frequency at which noise is measured.

the electrons given by (1). m is a constant depending on the trajectories. If the trajectories are linear, K is unity; if they are cycloids corresponding to a plane magnetron without space charge, we have $m=4$.

Actually, not all electrons are absorbed by the line. Measurements on distribution of collector and line current indicate that more than 80 per cent of electrons arrive on the line, and electronic efficiency should be:

$$\eta_e \geqq 0.8\left(1 - m\frac{V_j}{V_0}\right)$$

which can be transformed to:

$$\eta_e \geqq 0.8\left(1 - \frac{m}{4}\left(\frac{B_{cr}}{B}\right)^2\right),$$

B_{cr} being the cut-off magnetic field of a plane magnetron under the same conditions.

Circuit Efficiency: The circuit efficiency is given by the Q_v of the circuit and the external Q_{ext}:

$$\eta_c = \frac{Q_v}{Q_{ext} + Q_v}$$

Q_v is defined by:

$$Q_v = \frac{\omega \int_0^L W(y)dy}{P_L}$$

and Q_{ext} by:

$$Q_{ext} = \frac{\omega \int_0^L W(y)dy}{P_0}.$$

W is the stored energy per unit length, P_L the power loss in the line, and P_0 the output power. If γ_a is the attenuation of the line in Neper/cm, we have:

$$P_L = 2\gamma_a \int_0^L P'(y)dy,$$

where $P'(y)$, power propagating along the line, is related to $W(y)$:

$$P'(y) = W(y)v_g$$

and therefore:

$$Q_v = \frac{k_g}{2\gamma_a}, \quad k_g = \frac{\omega}{v_g}.$$

Q_{ext} is given by:

$$Q_{ext} = \frac{k_g \int_0^L W(y)dy}{W(0)}.$$

For small signal theory $W(y)$ can be obtained by the superposition of the waves with the propagation constants given by (2), and we obtain:

$$Q_{ext} = \frac{k_g}{2}\frac{\epsilon^{\gamma_a l} - 1}{\gamma_a} = Q_v(\epsilon^{\gamma_a l} - 1) \tag{14}$$

and:

$$\eta_c = \epsilon^{-\gamma_a l}. \tag{15}$$

If the attenuation is small (14) gives:

$$Q_{ext} = \frac{k_g}{2} l, \tag{16}$$

and found directly, if losses in the line are neglected.

Influence of the Coupling Impedance on the Efficiency: According to the theory neglecting space charge, efficiency should not depend on coupling impedance for

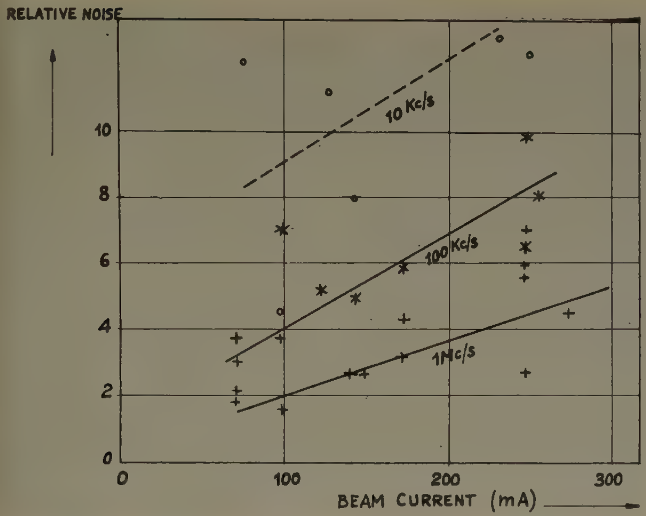


Fig. 13—Relative noise as a function of beam current.

high beam currents and should be a function only of the shape of trajectories, phase velocity of the circuit, and acceleration voltage. However, the first tubes tested have given a relatively low efficiency, much lower than predicted by theory.

It has been assumed space-charge phenomena have an important influence on efficiency (diocotron effect)[12] and if coupling impedance is high, space-charge effects should be negligible and efficiency should increase.

It can be seen that, contrary to the space-charge neglecting theory, efficiency increases rapidly with coupling impedance. The same occurs with the tuning range. As far as power is concerned, there is optimum value for the coupling impedance: an increase of coupling impedance decreases the thermal dissipation of the line and consequently the dc power which can be applied.

Rising-Sun Effect[13]

In the small signal theory, it is generally assumed that interaction takes place with one space harmonic. However there is the possibility that one space harmonic Γ_0 being coupled to the beam wave Γ_e, another space harmonic Γ_0' will be coupled to the beam wave $\Gamma_e - \omega_r/v_e$. This will occur if:

$$\Gamma_0 - \Gamma_0' = \frac{\omega_r}{v_e}. \tag{17}$$

The differences $\Gamma_0 - \Gamma_0'$ between two successive space harmonics being $2\pi/p$, where p is the pitch of the line, (17) implies that:

$$\frac{\omega_r}{v_e} = \frac{2\pi}{p}. \tag{18}$$

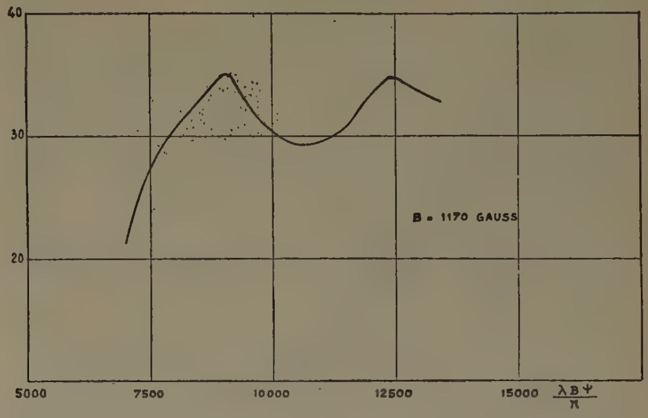


Fig. 14—Efficiency as function of voltage exhibiting rising-sun effect (average over 16 tubes).

If (18) is fulfilled, the space harmonic $\Gamma_0'' = \Gamma_0 + 2\pi/p$ will be coupled to the beam wave $\Gamma_e + \omega_r v_e$. However, this effect can be neglected, because of the low coupling impedance of the wave Γ_0''.

This simultaneous coupling of two space harmonics can occur in certain lines, e.g., interdigital lines, where asymmetrical and symmetrical space harmonics exist.[14,15] The first symmetrical space harmonic being normally used, interaction can occur with the first asymmetrical space harmonic which is in fact the fundamental space harmonic. For the symmetric space harmonics, the apparent pitch of the line is half the real pitch p. ψ being the phase angle along this apparent pitch for the first symmetric space harmonic, (18) can be expressed numerically in the following form:

$$\lambda B = \frac{10700\pi}{\psi}. \tag{19}$$

At the "cutoff" ($\psi = \pi$), this is the well-known condition for the "rising-sun effect" in the magnetron[16] characterized by a pronounced minimum in efficiency. As shown by Fig. 14 above, same phenomenon appears in the "M" Carcinotron for values of parameters satisfying (19). It is shown in Appendix B that simultaneously the starting current must exhibit a maximum. This can be seen on Fig. 15 (next page).

Characteristics of an "M" Carcinotron

Fig. 16 (page 422) shows an experimental setup for studying properties of "M" Carcinotron. Fig. 17 (page 422) shows same type of tube in an industrial form. To reduce the bulk of the tube, the line has been curved into a circular form. The electromagnet has been replaced by a permanent magnet. Fig. 18 (page 423) shows the performance charts measured on this tube, and Fig. 19 (page 423)

[12] P. Guénard and H. Huber, "Etude expérimentale de l'interaction par ondes de charge d'espace au sein d'un faisceau électronique se déplaçant dans des champs électrique et magnétique croisés," *Ann. Radioélect.*, vol. VII, p. 252; October, 1952.

[13] W. E. Willshaw, G. Mourier, and G. Guilbaud, "Effet de résonance électronique dans les tubes à champs électrique et magnétique croisés," *Compt. Rend. Acad. Sci.* (*Paris*), (in press).

[14] R. C. Fletcher, "A broad-band interdigital circuit for use in traveling-wave-type amplifiers," Proc. I.R.E., vol. 40, pp. 951–958; August, 1952.

[15] A. Leblond and G. Mourier, "Etude des lignes à barreaux a structure périodique," *Ann. Radioélect.*, vol. ix, p. 184; April, 1954.

[16] G. B. Collins, "Microwave Magnetrons," Radiation Lab. Series, McGraw-Hill Book Co., Inc., New York, N. Y., sec. 3.3; 1948.

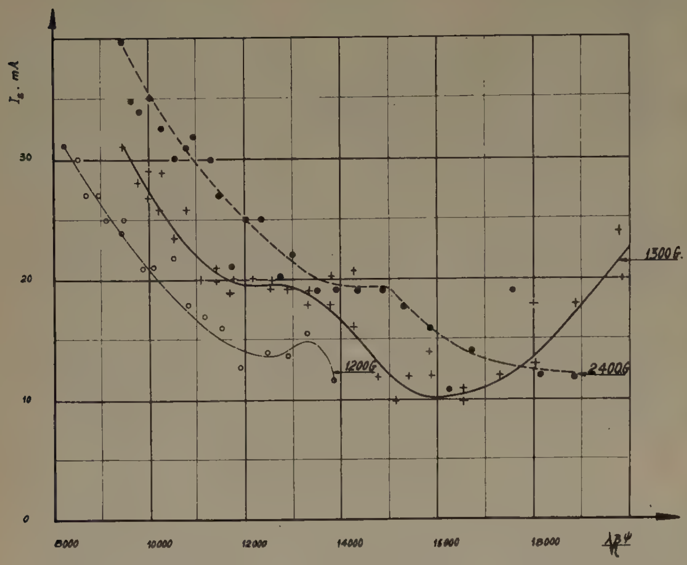


Fig. 15—Starting current curves exhibiting rising-sun effect.

Fig. 16—Experimental setup for studying a linear "M" Carcinotron.

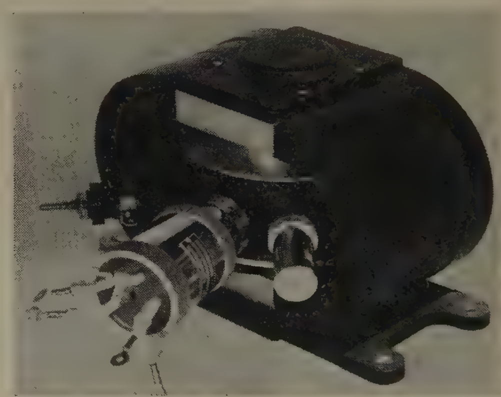


Fig. 17—Industrial model of an "M" Carcinotron.

the variation of power, efficiency and frequency with line voltage. These figures show possibility of obtaining, under practical conditions and for frequencies around 3,000 mc, power outputs of several hundred watts in a frequency range larger than half an octave and with efficiencies of the order of 40 per cent. In some cases, efficiencies in excess of 60 per cent have been measured.[8]

Conclusion

This paper shows that if the theory does not cover entirely the behavior of the "M" Carcinotron, in particular the space-charge effects, it nevertheless predicts the main features of this type of tube.

The main features of the "M" Carcinotron, as compared to other types of electronically tunable tubes, are: high efficiency, a fairly linear frequency–voltage characteristic, and a low pushing and pulling figure, together with a wide electronic range.

These features make the "M" Carcinotron particularly advantageous as a high-power electronically-tunable tube.

Appendix A

Without space charge, the motion of the electrons is determined by the field of the line, the components of which can be written:

$$E_x \epsilon^{j(\omega t - \Gamma_x)} = -\frac{\partial \Phi_L}{\partial x}, \qquad E_y \epsilon^{j(\omega t - \Gamma_y)} = -\frac{\partial \Phi_L}{\partial y}$$

with:

$$\Phi_L = \phi_L \frac{\sinh \Gamma y}{\sinh \Gamma y_0} \epsilon^{j(\omega t - \Gamma_x)}.$$

The equations giving the rf components of the motion are, for a linear trajectory $x = v_e \tau$, $y = y_0$:

$$-\xi^2 \delta x - j\xi\omega_r \delta y = -j\eta\Gamma\phi_L \tag{20}$$

$$j\xi\omega_r \delta x - \xi^2 \delta y = \eta\Gamma\phi_L K \tag{21}$$

$$(\xi = \omega - \Gamma v_e;\ K = \coth \Gamma y_0).$$

The coupling between the beam and the line is given by:

$$\Gamma - \Gamma_0 = j\frac{\vec{I}\cdot\vec{E}^*}{4P} = j\frac{\vec{I}\vec{E}^* R_c \Gamma_0^2}{2\Gamma\Gamma^*\phi_L\phi_L^*},$$

where R_c is the coupling impedance

$$R_c = \frac{E_x E_x^*}{2\Gamma_0^2 P}.$$

An infinitely thin sheet of the beam carrying the dc current dI_0 (which is taken positive) contributes to $\vec{I}\cdot\vec{E}^*$ through the following term:

$$-j\Gamma_e dI_0[\delta x E_x^* + \delta y E_y^*] = -\Gamma_e\Gamma^*\phi_L^* dI_0[\delta x - jK\delta y],$$

which gives, I_0 being the current carried by the beam:

$$j(\Gamma - \Gamma_0)\Gamma\phi_L = \frac{\gamma_M^2}{2}\left[\frac{\delta x}{K} - j\delta y\right] \tag{22}$$

where

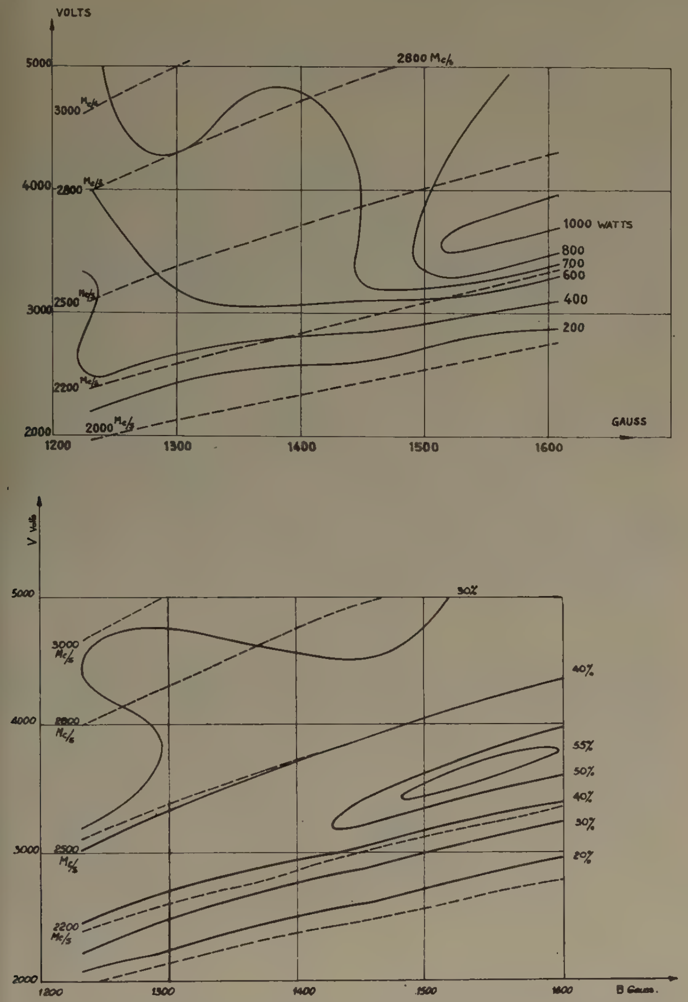


Fig. 18—Performance charts of an "M" Carcinotron: (a) Frequency and power output vs magnetic field and voltage. (b) Efficiency vs magnetic field and voltage.

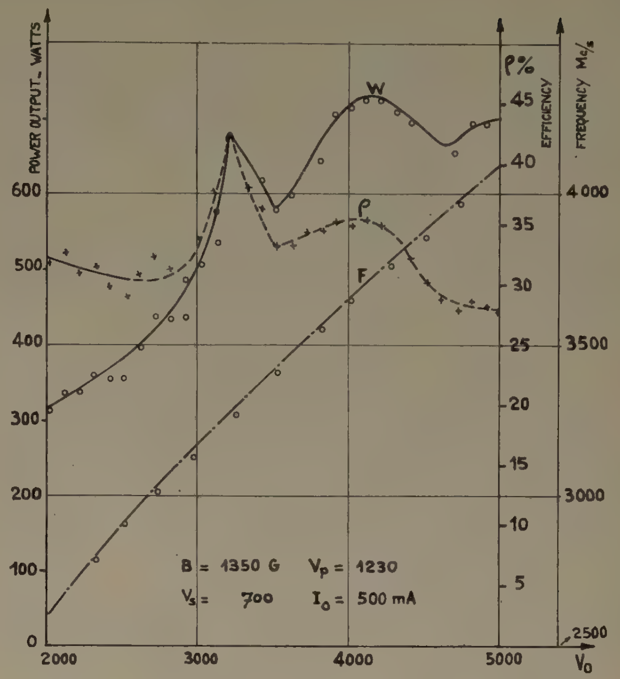


Fig. 19—Frequency, power output and efficiency as functions of line voltage.

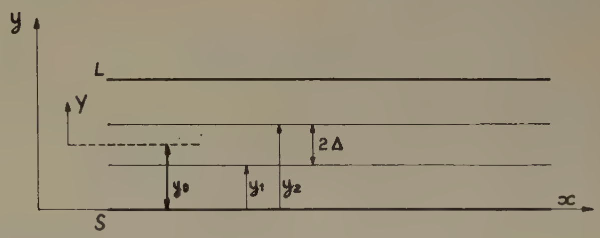


Fig. 20

$$\gamma_M{}^2 = \frac{I_0\Gamma_e\Gamma_0{}^2R_cK}{E_0}.$$

Eqs. (20), (21) and (22) determine five waves, one of which is:

$$\Gamma_5 = \Gamma_e \qquad \phi_L = 0 \qquad \delta x = jK\delta y \qquad \delta\dot{x} = \delta\dot{y} = 0.$$

Assuming

$$|\Gamma_e - \Gamma_0| \ll \frac{\omega_r}{v_e} \quad \text{and} \quad \gamma_M{}^2 \ll \left(\frac{\omega_r}{v_e}\right)^2,$$

$\Gamma_{1,2}$ are the two principal waves for which $|\xi| \ll \omega_r$. The propagation constants of these two waves are given by

$$(\Gamma - \Gamma_e)(\Gamma - \Gamma_0) = \gamma_M{}^2 \tag{23}$$

i.e.

$$\Gamma_{1,2} = \Gamma_m \pm \sqrt{\Gamma d^2 + \gamma_M{}^2} \tag{24}$$

with

$$\Gamma_m = \frac{\Gamma_e + \Gamma_0}{2}, \qquad \Gamma_d = \frac{\Gamma_e - \Gamma_0}{2}.$$

The two other waves correspond to $\xi = \pm\omega_r$. As compared to the waves $\Gamma_{1,2}$, they are weakly coupled to the field of the line, as seen from (20) and (21), which relate amplitudes of the field and of the electron motion.

The potential $\phi\epsilon^{j(\omega t - Fx)}$, from which derives the space-charge field of such a beam, can be calculated from the rf space-charge ρ and the surface density $-\rho_0\delta y$.

The space-charge density:

$$\rho = +\rho_0\left(\frac{\partial}{\partial x}\delta x + \frac{\partial}{\partial y}\delta y\right)$$

is equal to zero. The potentials ϕ_c inside, and ϕ_1, ϕ_2 outside the beam (Fig. 20 above) satisfy Laplace equations and are thus a linear combination of $\epsilon^{\Gamma y}$ and $\epsilon^{-\Gamma y}$.

If the sole and the line are remote enough from the beam ($\Gamma y_1 \gg 1$, $\Gamma(d - y_2) \gg 1$), the potentials are:

$$\phi_1 = A\epsilon^{\Gamma y}$$

$$\phi_2 = B\epsilon^{-\Gamma y}$$

$$\phi_c = C\epsilon^{\Gamma y} + D\epsilon^{-\Gamma y}.$$

The boundary conditions at the two edges of the beam give

$$\phi_c = \frac{-\rho_0 \delta y_2}{2\Gamma\epsilon_0} \epsilon^{\Gamma(y-y_2)} + \frac{\rho_0 \delta y_1}{2\Gamma\epsilon_0} \epsilon^{\Gamma(y_1-y)}.$$

Assuming $\Gamma\Delta \ll 1$, ϕ_c takes the simplified form:

$$\phi_c = -\psi L \frac{\Omega_0^2 \Gamma}{\omega_r \xi} (K\Delta + Y)(1 - \Gamma\Delta). \tag{25}$$

With space charge, the equations of motion are:

$$\delta x'' - \omega_r \delta \dot{y} = -j\eta\Gamma\left(\phi_L \frac{\sinh \Gamma y}{\sinh \Gamma y_0} + \phi_c\right)\epsilon^{j\xi' \tau}$$

$$\delta \ddot{y} + \omega_r \delta \dot{x} = \Omega_0^2 \delta y + \eta \frac{\partial}{\partial y}\left[\phi_L \frac{\sinh \Gamma y}{\sinh \Omega y_0} + \phi_c\right]\epsilon^{j\xi' \tau}$$

with

$$\xi' = \omega - \Gamma v_e' - \Gamma \frac{\Omega_0^2}{\omega_r} Y$$

$$v_e' = v_e - \frac{\Omega_0^2}{\omega_r}\Delta\left(1 - \frac{2y_0}{d}\right).$$

Introducing in these equations the value of ϕ_c given by (25), and assuming:

$$\Gamma \frac{\Omega_0^2 \Delta}{\omega_r v_e} = \alpha \ll \gamma_M,$$

these equations give

$$(\Gamma - \Gamma_0)(\Gamma - \Gamma_e) = \gamma_M^2\left(1 - \frac{\Omega_0^2 \Gamma\Delta}{\omega_r \xi}\right), \tag{26}$$

ξ being the value of $\omega - \Gamma v_e$, given by the theory which neglects space charge. The propagation constants of the two principal waves are thus given by:

$$\Gamma = \Gamma_m \pm \sqrt{\Gamma_d^2 + \gamma_M^2\left(1 - \frac{\alpha}{\Gamma_d \mp \sqrt{\Gamma_d^2 + \gamma_M^2}}\right)}. \tag{27}$$

Appendix B

In Appendix A, it has been supposed that one space harmonic was coupled to the beam. Let us suppose now that the space harmonics are coupled to the beam corresponding to propagation constants Γ_0 and $\Gamma_0' = \Gamma_0 - 2\pi/p$, p being the pitch of the line. Both space harmonics will be strongly coupled to the beam if:

$$\Gamma_e \sim \Gamma_0, \qquad \Gamma_e - \frac{\omega_r}{v_e} \sim \Gamma_0 - \frac{2\pi}{p}$$

that is if:

$$\frac{\omega_r}{v_e} = \frac{2\pi}{p}.$$

The amplitudes of these two space harmonics are related by the properties of the line, and for the second wave, the propagation constant will be $\Gamma' = \Gamma - 2\pi/p$ and the amplitude $k\phi_L$. The equations of motion (20) and (21) hold for the first space harmonic. For the second space harmonic, the equations of motion are:

$$-\xi'^2 \delta x' - j\xi' \omega_r \delta y' = -j\eta\Gamma' k\phi_L \tag{28}$$

$$j\xi' \omega_r \delta x' - \xi'^2 \delta y' = \eta\Gamma' k\phi_L K', \tag{29}$$

with:

$$\xi' = \xi + \omega_r.$$

The equation of coupling between the line and the beam must take into account both space harmonics, that is:

$$\vec{I}\cdot\vec{E}^* = -jI_0\Gamma_e[\delta x E_x^* + \delta y E_y^* + \delta x' E_x'^* + \delta y' E_y'^*]$$

$$= -\Gamma_e \Gamma^* \phi_L^* I_0 \left[(\delta x - jK\delta y) + \frac{\Gamma'^*}{\Gamma^*} k(\delta x' - jK'\delta y')\right]. \tag{30}$$

Eq. (23) becomes

$$(\Gamma - \Gamma_e)(\Gamma - \Gamma_0) = \gamma_M^2(1 - S),$$

where

$$S = \frac{1 + K'^2}{4K} |k|^2 \left|\frac{\Gamma'}{\Gamma}\right|^2,$$

showing that the starting current is increased by the factor $1/\sqrt{1-S}$.

There are now two waves uncoupled to the beam ($\phi_L = 0$) corresponding to $\xi = 0$, $\xi' = \omega_r$, the four factors δx, δy, $\delta x'$, $\delta y'$ being related by two equations:

$$\delta x - jK\delta y + \frac{\Gamma'}{\Gamma} k(\delta x' - jK'y') = 0$$

$$\delta x' = -j\delta y'.$$

Power Flow in Electron Beam Devices*

W. H. LOUISELL† AND J. R. PIERCE†, FELLOW, IRE

Summary—This paper discusses power flow in devices in which electrons are constrained to move in the z direction only. Besides the electromagnetic power flow given by Poynting's vector, there is a kinetic power flow per unit area in the z direction. In a linear system equivalent to the electron beam at low levels of operation this power flow is

$$P_R = \frac{1}{2}\frac{m}{e}(-J_0 + J)(u_0^2 + 2u_0 v).$$

Here $-J_0$ and J are the dc and instantaneous ac convection current densities and u_0 and v are the dc and instantaneous ac velocities.

The electromagnetic power must be calculated including all fields due to the presence of the beam. In the case of space-charge waves, the electromagnetic power flow adds to or subtracts from the kinetic power flow. If the electric field is purely longitudinal, H is zero, and the electromagnetic power flow is zero.

IN ELECTRON beam devices such as traveling-wave tubes and klystrons there is not only electromagnetic power flow, but also power flow associated with the kinetic energy of the electrons; we may call this latter kinetic power flow. This note discusses power flow in beam devices, and particularly power flow at low signal levels for which linearized equations can be used to describe the operation of the devices.

Maxwell's equations yield a relation which may be written

$$\nabla \cdot P_e + \frac{\partial}{\partial t} W_e + E \cdot J = 0, \tag{1}$$

where

$$P_e = E \times H \tag{2}$$

$$W_e = \tfrac{1}{2}\mu H \cdot H + \tfrac{1}{2}\epsilon E \cdot E. \tag{3}$$

Here E, H and J are vectors; they are the electric field, the magnetic field, and the convection current density. P_e is the Poynting vector, which may be interpreted as electromagnetic power flow per unit area and W_e, a scalar, is the electromagnetic stored energy per unit volume associated with the total electric and magnetic fields, in the presence of the electrons.

Consider a case in which the only convection current (other than convection current at the surface of perfect conductors, for which $E \cdot J = 0$) is due to a cloud of electrons of charge density ρ, the electrons being free to move in the z direction only and having at any point a common velocity v. The nonrelativistic equation of motion is

$$\frac{\partial v}{\partial t} + v\frac{\partial v}{\partial z} = -\frac{e}{m}E_z$$

$$E_z = -\frac{m}{e}\left[\frac{\partial v}{\partial t} + v\frac{\partial v}{\partial z}\right]. \tag{4}$$

We also have relations

$$J = J_z = \rho v \tag{5}$$

$$\nabla \cdot J + \frac{\partial \rho}{\partial t} = \frac{\partial J_z}{\partial z} + \frac{\partial \rho}{\partial t} = 0. \tag{6}$$

Consider the term $E \cdot J$ in (1); using (4) we can rewrite it

$$E \cdot J = -\frac{m}{e}\left[\frac{\partial v}{\partial t} + v\frac{\partial v}{\partial z}\right] J. \tag{7}$$

A little differentiation, together with (5) and (6), shows that

$$E \cdot J = \frac{\partial W_k}{\partial t} + \frac{\partial P_k}{\partial z}, \tag{8}$$

where

$$W_k = -\frac{1}{2}\frac{m}{e}\rho v^2 \tag{9}$$

$$P_k = (P_k)_z = -\frac{1}{2}\frac{m}{e}Jv^2. \tag{10}$$

Thus, we can rewrite (1)

$$\nabla \cdot (P_e + P_k) + \frac{\partial}{\partial t}(W_e + W_k) = 0. \tag{11}$$

Here of course $\nabla \cdot P_k = \partial (P_k)z/\partial z$. Eq. (11) represents the conservation of energy. As P_e and W_e are electromagnetic power flow and electromagnetic energy, so P_k and W_k are kinetic power flow and kinetic energy.

In dealing with the low-level operation of electron beam devices we do not use (4) and (5) but, rather, we use linearized equations and use

$$E_z = -\frac{m}{e}\left[\frac{\partial v}{\partial t} + u_0\frac{\partial v}{\partial z}\right] \tag{4a}$$

$$J = J_z = -\rho_0 v + u_0 \rho. \tag{5a}$$

Here u_0 is the average electron velocity and v is a small ac velocity component; $-\rho_0$ is the average charge density and ρ is a small ac component. We may regard (4a) and (5a) and (6) as the equations of an "equivalent" linear system whose behavior is the same as the behavior of the actual nonlinear system at low levels of operation. We may ask, what is the correct expression for power flow and stored energy in the equivalent linear system.

In the linear system

* Original manuscript received by the IRE, November 22, 1954; revised manuscript received, January 17, 1955.
† Bell Telephone Labs, Inc., Murray Hill Lab., Murray Hill, N.J.

$$E\cdot J = -\frac{m}{e}\left[\frac{\partial v}{\partial t} + u_0\frac{\partial v}{\partial z}\right]J. \tag{12}$$

We find that $(E\cdot J)$ can be expressed in the form (8) if we define

$$P_k = -\frac{1}{2}\frac{m}{e}(-J_0 + J)(u_0^2 + 2u_0v) \tag{13}$$

and

$$W_k = -\frac{1}{2}\frac{m}{e}\left[-\rho_0(u_0^2+2u_0v+v^2)+\rho(u_0^2+2u_0v)\right]. \tag{14}$$

These expressions are not the result of a linearized expansion; (13) and (14) were chosen so that (11) holds for the linear system with P_k and W_k so defined. We will run into no contradictions if we interpret P_k and W_k as kinetic power flow of the beam per unit area and kinetic energy in the beam per unit volume respectively.

In dealing with amplifiers we deal with signals which vary sinusoidally with time. In the linear system we can consider each frequency component of the ac quantities separately. Let us then think of the ac quantities as complex quantities containing a factor $e^{j\omega t}$. Then the average power flow in the z direction per unit area will be

$$P_z = \frac{1}{4}\left[(E\times H^* + E^*\times H)_z - \frac{m}{e}\,u_0(vJ^* + v^*J)\right]. \tag{15}$$

In this expression E, H, v and J are peak values. We can get the total power flow in the z direction by integrating the z component of P as given by (15) with respect to x and y.

Let us now consider the power flow in space-charge waves. In the case of true plasma waves, in which all the displacement current is in the direction of electron motion, the displacement current is equal and opposite to the convection current. There is no net current in the z direction and no electromagnetic power flow, since H is zero. In this case the total power flow of the wave is the kinetic power flow, the second term of (15).[1]

At the other extreme, we can consider space-charge waves in an electron stream in a tube narrow compared with the space-charge wave length. In this case the displacement current in the z direction is negligible, and there is an electromagnetic power flow.

In the case of a space-charge wave, the variation of the ac quantities with respect to z can be expressed by a factor $e^{-j\beta z}$. Let us consider slow space-charge waves, for which the electric field can be expressed with adequate accuracy in terms of the gradient of a potential V, so that

$$E_z = -\frac{\partial V}{\partial z} = j\beta V. \tag{16}$$

Let us consider the electromagnetic power flow in the z direction per unit area, P_{e1} associated with the convection current J.[2]

$$P_{e1} = \tfrac{1}{4}(VJ^* + V^*J).$$

Using (16) and (12) to express V in terms of v, we find this to be

$$P_{e1} = -\frac{1}{4}\frac{m}{e}u_0\left[\frac{\omega - \beta u_0}{\beta u_0}\right][vJ^* + v^*J]. \tag{17}$$

We see from (15) that the ratio of P_{e1} to the kinetic power density P_k is

$$\frac{P_{e1}}{P_k} = \frac{\omega - \beta u_0}{\beta u_0}; \tag{18}$$

for small space charges, very nearly

$$\omega - \beta u_0 = \pm\,\omega_q \tag{19}$$

$$\beta u_0 = \omega. \tag{20}$$

Here ω_q is called the *effective plasma frequency*. Thus, for small space charge, approximately

$$\frac{P_{e1}}{P_k} = \pm\frac{\omega_q}{\omega}. \tag{21}$$

In terms of the traveling-wave tube parameters Q and C

$$\frac{P_{e1}}{P_k} = \pm\,(2\sqrt{QC})C. \tag{22}$$

For realistic space charge waves, the electromagnetic power flow will lie between the extremes of 0 (electric field purely longitudinal) and P_{e1} (longitudinal electric field negligible compared with transverse electric field). Thus, we see that when space charge is small ($\omega_q/\omega \ll 1$, $C \ll 1$) the electromagnetic power of the space-charge wave is negligible compared with the kinetic power. However, for large space charge the electromagnetic power may be important except in cases of negligible transverse electric field.

When the space charge is large, (19) does not hold unless the transverse electric field is negligible, and (20) does not hold at all. Thus, to calculate the power accurately one must integrate (15) across the system.

One can also use (15) to calculate the small-signal power flow in traveling wave tubes. Here one must include the total electromagnetic power flow associated with both beam and circuit currents as well as the kinetic power flow.

[1] The kinetic power and the fact that it is negative for the slow space-charge wave, were treated in a paper by L. J. Chu, presented at the IRE Electron Devices Conference, University of New Hampshire, June, 1951.

[2] S. A. Schelkunoff, "Electromagnetic Waves," D. Van Nostrand Co., New York, p. 79; 1943; S. A. Schelkunoff and H. T. Friis, "Antennas, Theory and Practice," John Wiley and Sons, New York, pp. 76–78; 1952.

There is quite a different approach toward evaluating the power at low levels, in which one deals not with linear equations describing an equivalent linear system, but with the actual nonlinear equations at low levels.[3] In this case one must carry the solution beyond the first order. The final results, however, agree with those given here.

[3] L. R. Walker, "Power Flow in Electron Beams," to be published in the *Jour Appl. Phys.*

R. W. Gould of the California Institute of Technology[4] has evaluated the power flow and stored energy in the case of electrons free to move in any direction and in which $H=0$ (plasma oscillations).

The authors are much indebted to L. R. Walker for contributions at all stages in the evolution of this paper.

[4] R. W. Gould, California Institute of Technology, Electron Tube and Microwave Laboratory Quarterly Status Report No. 5, p. 15; April 1, 1954 to June 30, 1954.

The Effective Surface Recombination of a Germaniun Surface with a Floating Barrier*

A. R. MOORE† AND W. M. WEBSTER†, SENIOR MEMBER, IRE

Summary—**The effect of heavily doped (alloyed) *p*-type and *n*-type surface layers on *n*-type base, and of metallic plating on *n*-type base, on the surface recombination velocity *s* has been computed on the basis of one-dimensional junction theory. The results indicate that *s* should be of the order 1 cm/sec for the heavily doped surfaces, and several thousand cm/sec for the electroplated surface. The low *s* comes about for the same reason that the injection efficiency of alloy junctions is high; the alloy junction is a very efficient emitter of minority carriers into the base and a poor acceptor of majority carriers from the base because of the high doping level in the alloyed region. Since recombination in the surface layer of minority carriers from the base requires both majority and minority carriers, the restriction of the flow of either reduces the surface recombination.**

However, measurements of *s* by diffusion and pulse methods on alloy junction surfaces indicate that their apparent recombination is almost the same as adjacent untreated surface, e.g., 300–500 cm/sec. It is shown that lateral current flow, due to minority carrier gradients parallel to the junction interface, and neglected in one-dimensional theory, gives rise to circulating currents which translate the minority carriers to the nearest high recombination surface. This hole translation property of the floating *p*-layer is used to explain the erroneously high lifetimes often observed by diffusion measurements on silicon and *p*-type germanium, and certain discrepancies in effective life measurement on completed transistors.

General Discussion

THE RATE OF recombination of minority carriers at free surfaces often plays a dominant role in determining the characteristics of semiconductor devices. For example, the current amplification-factor of a transistor is usually determined by surface recombination more than by any other quantity.[1,2] Thermal generation of minority carriers, which is related to both surface and volume recombination, results in saturation current in rectifiers and transistors. In many devices, the free surfaces contribute most of this generally undesirable saturation current. In some photoconductor devices, surface recombination limits sensitivity.

Surface recombination can be expressed quantitatively through the surface recombination velocity *s*.[3] The rate at which minority carriers recombine is proportional to the product of their concentration and *s*. In theory *s* is a characteristic of the surface and may have any value between zero and thermal velocity (about 10^7 cm/sec). Experiments on germanium surfaces show that *s* depends on the surface treatment and that values ranging from about 50 cm/sec to several thousand cm/sec may be obtained by different chemical treatments.[1,4] To reduce surface recombination, we are interested in treatments which result in very low values of *s*.

A variety of models of the surface which might give low surface recombination velocity can be imagined. Three, experimentally attainable with reasonable certainty, are illustrated in Fig. 1 (next page). They all imply the addition or production of a film on the surface which has different electrical characteristics from the bulk. These three possibilities are: (1) a metallic film, (2) a layer of opposite conductivity type, and (3) a layer of the same conductivity type but of higher conductivity. Plating techniques permit a metallic layer to be formed and the change of conductivity may be accom-

* Original manuscript received by the IRE, December 3, 1954; revised manuscript received, January 11, 1955.
† RCA Labs, Princeton, N.J.
[1] A. R. Moore and J. I. Pankove, "Effect of junction shape and surface recombination on transistor current gain," Proc. I.R.E., vol. 42, pp. 907–913; June, 1954.
[2] W. M. Webster, "On the variation of junction transistor current amplification factor with emitter current," Proc. I.R.E., vol. 42, pp. 914–920; June, 1954.

[3] W. Shockley, "Holes and Electrons in Semiconductors," D. Van Nostrand Co., New York, p. 321; 1950.
[4] E. M. Conwell, "Properties of silicon and germanium," Proc. I.R.E., vol. 40, pp. 1327–1337; November, 1952.

plished by alloying[5] or by diffusing impurities into the surface.[6] While many other surface models are possible, these three are easily analyzed and should permit comparison of theory with experiment. The present work evaluates the possibilities for reducing s by these means in terms of a simple one-dimensional analysis and discusses some preliminary experimental results.

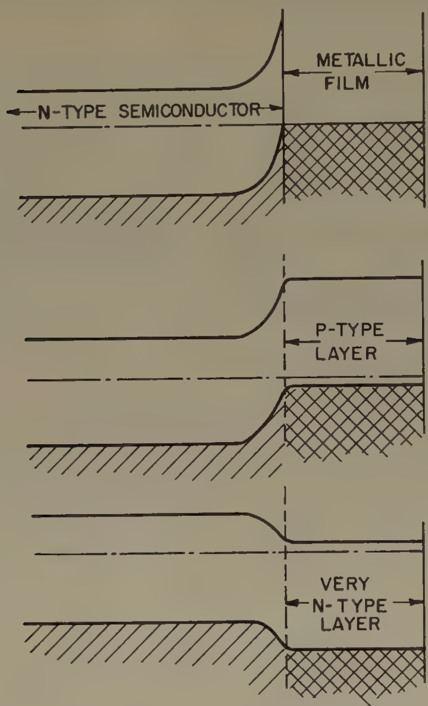


Fig.1—Energy level diagrams for three possible types of surface barrier.

Theory

In this section, equations are given which may be used to predict the rate of surface recombination for metallic, n, and p-type films on n-type material. The same reasoning can of course be applied to films on p-type material. The treatment is one-dimensional for simplicity and is therefore subject to the assumption that no parameters vary appreciably along the surface. The discussion of experimental results which follows shows that this condition can be troublesome in actual practice.

One can see intuitively why surface layers such as these are hopeful. In all cases, a barrier exists near the surface to one type of carrier or the other. Since both holes and electrons must be present for recombination, restraining the flow of either should reduce surface recombination.

The approach of this section is as follows. First, an equivalent surface recombination velocity s is defined for p- and n-type surface layers and evaluated in terms of recombination in the film. Following this an equation for s for a metallic surface is given and an approximate value computed. Finally, a relation between s and γ ("emitter efficiency" of the layer if it were used as the emitter of a transistor) is demonstrated.

n- and p-Type Layers

Definition of Equivalent s: The equivalent surface recombination velocity for a surface with a semiconducting layer on it will be called s and will be defined as follows:

Consider the situation of an n-type semiconductor with a surface layer d cm thick and composed of the same material but of different conductivity. The energy band configuration for both cases of interest, and the pertinent parameters, are labeled in Fig. 2. Holes and electrons recombine in the surface layer by both surface and volume recombination. To maintain nonequilibrium steady-state densities of minority and majority carriers in the surface layer, holes and electrons must flow in equal numbers from the bulk into the surface layer.

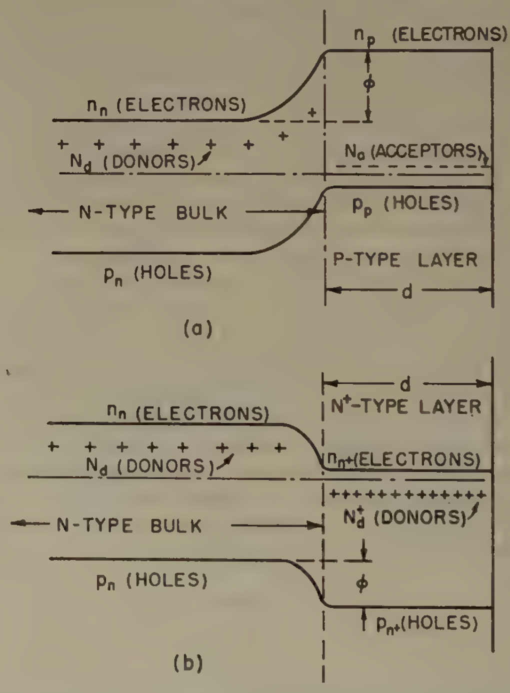


Fig. 2—Detailed energy level diagram for (a) p-type layer on n-type base and (b) strongly n-type layer on an n-type base.

Further, this flow must equal the net recombination rate in the surface layer. This results in two equal current densities J_e and J_p. The effective surface recombination velocity will be defined as

$$s = \frac{J}{q(p_n - p_0)}; \tag{1}$$

where $J = J_e = J_p$, p_0 is the equilibrium value of p_n, and

[5] R. R. Law, C. W. Mueller, J. I. Pankove, and L. D. Armstrong, "A developmental germanium p-n-p junction transistor," Proc. I.R.E., vol. 40, pp. 1352–1357; November, 1952.

[6] R. N. Hall and W. C. Dunlap, "P-N junctions prepared by impurity diffusion," *Phys. Rev.*, vol. 80, pp. 467–468; November, 1950.

q is the electronic charge ($p_n - p_0$ is the excess hole density in the bulk). This is the value of surface recombination velocity which one would measure by any of our present techniques.[7-9]

So that the general considerations may apply to either p- or n-type layers we will identify the minority carrier density in the surface layer with the letter m, and its equilibrium value with m_0. J is determined by the minority carrier lifetime in the surface layer τ, the surface recombination velocity for minority carriers s_m at the actual outer surface [as distinguished from the effective s of (1)]; the thickness of the surface layer d, and the excess minority carrier density $(m - m_0)$ in the surface layer. The minority carriers determine the recombination rate in the surface layer regardless of whether they are electrons or holes.

Two approximate expressions for J are

$$J = q(m - m_0)\left(\frac{d}{\tau} + s_m\right), \tag{2a}$$

when $d < L_m$ (i.e., for thin layers),

$$J = q(m - m_0)\left(\frac{L_m}{\tau}\right) = q(m - m_0)\frac{D_m}{L_m}, \tag{2b}$$

when $d > L_m$. D_m and L_m are the minority carrier diffusion coefficient and diffusion length, respectively, in the surface layer.

Combining (2a) and (2b) with (1):

$$s = \left(\frac{d}{\tau} + s_m\right)\frac{(m - m_0)}{(p_n - p_0)} \tag{3a}$$

when $d < L_m$, and

$$s = \frac{D_m}{L_m}\frac{(m - m_0)}{(p_n - p_0)} \tag{3b}$$

when $d > L_m$.

The ratio of the steady-state excess minority carrier densities, $(m - m_0)/(p_n - p_0)$, are now calculated for n- and p-type layers.

p-type Surface Layer: The ratio $(m - m_0)/(p_n - p_0)$ depends on the conductivities of the bulk and surface layer with acceptor density N_a as shown in Fig. 2(a). The electron density in the p-type material n_p is the minority carrier density m in (3a) and (3b). Thus, what is desired is $n_p - n_0$ to replace $m - m_0$ in the general expressions for s.

Four basic equations link the densities of holes, electrons, donors, and acceptors with the barrier height, ϕ:

$$n_n = N_d + p_n, \tag{4a}$$

$$n_p + N_a = p_p, \tag{4b}$$

$$n_n e^{-q\phi/kT} = n_p, \tag{4c}$$

and

$$p_n = p_p e^{-q\phi/kT}. \tag{4d}$$

The first two equations indicate charge neutrality in the surface layer and bulk, and the second pair relate the hole and electron concentrations on either side of the boundary. The only assumptions involved in applying these equations are (1) net electrical neutrality except in the depletion layer at the boundary, and (2) s reasonably small (compared to thermal velocity). Both are sufficiently satisfied. Eq. (4) may be combined to yield an expression linking n_p and p_n:

$$p_n^2 + p_n N_d + n_p^2 N_a, \tag{5a}$$

and the same form applies to the equilibrium densities:

$$p_0^2 + p_0 N_d = n_0^2 + n_0 N_a. \tag{5b}$$

Combining these to yield the form needed to calculate s is difficult. However, we may make some simplifying assumptions. In the event that N_a is very large (a very p-type surface), n_p^2 is negligible compared to $n_p N_a$. If, in addition, $N_d \gg p_n$, we can write very simply

$$\frac{n_p - n_0}{p_n - p_0} \approx \frac{N_d}{N_a}. \tag{6a}$$

N_d/N_a may now be substituted into (3a) and (3b) in place of $(m - m_0)/(p_n - p_0)$ to calculate s. Under conditions of high injected hole density in the bulk, p_n may not be negligible compared to N_d. However, it will then be great compared to p_0 and we may write

$$\frac{m - m_0}{p_n - p_0} \approx \frac{n_p - n_0}{p_n} \approx \frac{P_n + N_d}{N_a}. \tag{6b}$$

Thus, at high levels of p_n, s will increase linearly with hole density in the n-type material.

Substitution of (6a) into (3a) and (3b) yields:

$$s = \left(\frac{d}{\tau} + s_m\right)\frac{N_d}{N_a} \text{ for thin layers,} \tag{7a}$$

and

$$s = \frac{D_m}{L_m}\frac{N_d}{N_a} \text{ for thick layers (compared to } L_m). \tag{7b}$$

L_m and D_m apply to electrons in the surface layer. These equations apply for low injection levels ($p_n \ll N_d$).

n^+ Surface Layer: The form of the equivalent expressions for s for the case of a very n-type layer is similar to the foregoing and may be derived in much the same way. Here, holes are the minority carriers in both the surface layer and the bulk. The symbol + refers to characteristics in surface layer as indicated in Fig. 2b.

We can write four equations similar to those used for the case of the p-type surface:

$$n_n = p_n + N_d \tag{8a}$$

$$n_{n+} = p_{n+} + N_d^+ \tag{8b}$$

$$n_n = n_{n+}e^{-q\phi/kT} \tag{8c}$$

[7] L. B. Valdes, "Measurement of minority carrier lifetime in germanium," Proc. I.R.E., vol. 40, pp. 1420–1423; November, 1952.
[8] S. Lederhandler and L. Giacoletto, "Measurement of minority carrier lifetime and surface effects in junction devices," to be published.
[9] D. T. Stevenson, and R. J. Keyes, *Bull. Am. Phys. Soc.*, vol. 29, p. 18; March, 1954.

$$p_{n+} = p_n e^{-q\phi/kT}. \tag{8d}$$

These equations are of the same form as (4). The difference is that n_p, n_0, and n_a of (5a) and (5b) are replaced by p_{n+}, p_{0+}, and N_d^+, respectively. Subject to similar assumptions, the solutions will be of the same form as (7). Thus we have:

$$s = \left(\frac{d}{\tau} + s_m\right)\frac{N_d}{N_d^+}, \quad \text{when} \quad d < L_m, \quad \text{and} \tag{9a}$$

$$s = \frac{D_m}{L_m}\cdot\frac{N_d}{N_d^+}, \quad \text{when} \quad d > L_m, \tag{9b}$$

where D_m and L_m apply to holes in the surface layer.

General Expressions for s: In the case of a surface layer which is thick compared to a minority carrier, diffusion length within it, we have (7b) and (9b). We may now use the Einstein relationships ($D_p = kT\mu_p/q$ and $D_n = kT\mu_n/q$) and introduce $\sigma_b \approx q\mu_n N_d$ (the conductivity of the bulk material) and σ_s (the conductivity of the surface layer). For the n^+ type layer, $\sigma_s = q\mu_n N_d^+$, while for the p-type layer, $\sigma_s = q\mu_p N_a$. By manipulation, both (7b) and (9b) become

$$s = \frac{D_p}{L_m}\cdot\frac{\sigma_b}{\sigma_s}; \qquad (d > L_m). \tag{10}$$

It should be emphasized that D_p is the hole diffusion coefficient in the surface layer. Because of impurity scattering this may be lower than D_p in the bulk.

Similarly, a generalized expression for (7a) and (9a) may be written which applies to thin layers:

$$s = \left(\frac{d}{\tau} + s_m\right)\frac{\sigma_b}{\sigma_s}\cdot\frac{\mu_s}{\mu_b} \quad \text{when} \quad d < L_s. \tag{11}$$

Here, τ is the minority lifetime in the surface layer, s_m is the surface recombination velocity at the actual outer surface of the layer, μ_s and μ_b are majority carrier mobilities in the surface layer and bulk, respectively. The valve μ_s will be less than the value measured in relatively pure material because of impurity scattering, and possibly scattering at the surface.

Evaluation of p and n Layers: It is difficult to evaluate (11) since τ and s_m for highly doped semiconductors have not been measured. If we assume, however, that d is sufficiently small that d/τ is dominated by s_m, and assume further that s_m is of the same order of magnitude as surface recombination values already obtained (say 1,000 cm/sec, to be conservative), then s may be of the order of 1 cm/sec when $\sigma_b/\sigma_s = 10^{-3}$. Eq. 10 is easier to consider because the term $\sigma_s L_m$ is the familiar one which enters into the expression for the efficiency of an emitter. Previous work suggests that $\sigma_s L_m$ has the value of about 1.6 mhos in alloy junctions in germanium.[2] Now, if σ_b is assumed to be 0.2 mhos/cm and $D_p \approx 6$ cm²/sec (consistent with heavily doped germanium), then $s = 0.75$ cm/sec. This is a very hopeful result. There is no reason to prefer a p-type layer to an n-type layer of equal conductivity as far as values of s are concerned. However, the latter would be preferable in many cases for other reasons (e.g., there would be no tendency to produce surface short-circuit paths from emitter to collector of a transistor).

Metal Films

The above analysis only applies when the surface layer is also a semiconductor and has the same energy gap as the bulk. To add to the picture, surface layers with different energy gaps should be discussed. In particular, the case of a metal film deserves attention.

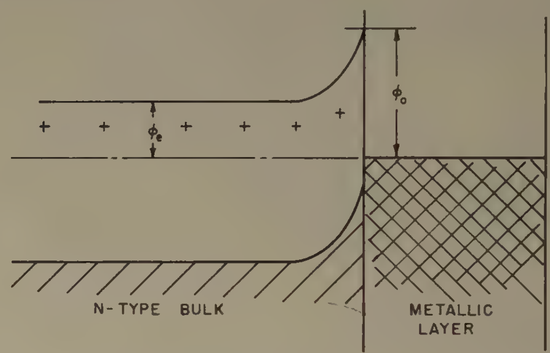


Fig. 3—Detailed energy level diagram for a metallic layer on an n-type base.

An expression for s can be computed for the case of a metal-semiconductor contact such as illustrated in Fig. 3. The derivation is straightforward and so will not be given; the result is:

$$s \approx \frac{\sigma_b^2}{\sigma_i^2}\,\frac{(1+b)^2}{b^2}\,\frac{\bar{c}}{4}\,e^{-q(\phi_0-\phi_e)/kT}. \tag{12}$$

Here, σ_i is the conductivity of the intrinsic semiconductor, $\bar{c}$ is mean thermal velocity ($\approx 10^7$ cm/sec at 300 degrees K). ϕ_0 and ϕ_e are labeled in the figure, and $b = \mu_n/\mu_p$. This equation is derived assuming diffusion flow for holes and "diode" flow for electrons crossing the barrier.[10,11]

Evaluation of (12) requires a knowledge of $(\phi_0 - \phi_e)$. [Schwartz and Walsh have estimated this quantity to be 0.3 electron volt for 5 ohm-cm germanium in connection with the surface-barrier transistor.[11]] If N_d for 5 ohm-cm n-type germanium and 0.3 electron volt for $(\phi_0 - \phi_e)$ are substituted into (12), a value for s of 3,500 may be computed. This calculated value is of the same order as the surface recombination velocity measured for a copper-plated surface (7,400 cm/sec.[1]). Even if (12) is not

[10] W. E. Bradley, "Principles of the surface-barrier transistor," Proc. I.R.E., vol. 41, pp. 1702–1706; December, 1953.
[11] R. F. Schwarz and J. F. Walsh, "Properties of metal to semiconductor contacts," Proc. I.R.E., vol. 41, pp. 1715–1720; December, 1953.

strictly applicable, due to inversion layer effects, at present the evidence suggests that metal films will give values of surface recombination velocity which are much larger than those that are easily attained with chemical treatments.

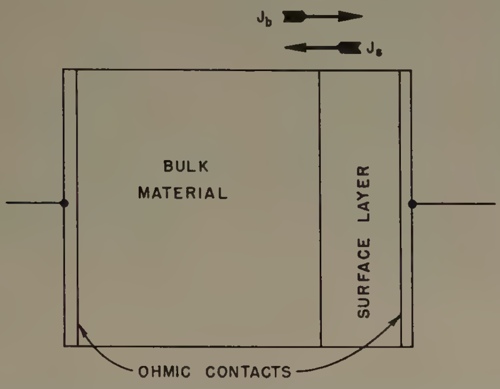


Fig. 4—Hypothetical diode formed by connection to the bulk material and to the surface layer. The arrows show the direction of carrier flow when the diode is biased in the forward direction.

Relation to Emitter Efficiency

Consider Fig. 4 which shows a diode made by connection to the semiconductor bulk and to the surface layer. The currents J_b and J_s labeled according to the direction of carrier flow when the diode is biased in the forward direction. Their ratio defines the emitter efficiency γ of a transistor which might be made using the surface layer as an emitter and the bulk material as the base region. The approximate relation is

$$\frac{1-\gamma}{\gamma} = \frac{J_b}{J_s}\cdot\frac{W_b}{L_p}, \tag{13}$$

where W_b is the emitter-collector spacing of the transistor.[12] For a p-n-p transistor,

$$\frac{1-\gamma}{\gamma} = \frac{\sigma_b W_b}{\sigma_s L_p},$$

where L_p is the hole diffusion length in the emitter. This is also the result of multiplying (10) by W_b/D_p, since L_p and L_m are identical.

$$\frac{1-\gamma}{\gamma} = s\frac{W_b}{D_p}\cdot \tag{14}$$

This relation is actually quite general. It applies to the metallic film of the surface-barrier transistor and even for an n^+ surface layer and what might be called n^+-n-n^+ transistor. In fact, (14) may be derived directly from the diode equations in such a way that the relation between s and γ emerges as fundamental. While such a procedure suggests a more direct way of deriving s for different surface layers, it is less easy to consider in physical terms than the preceding development. The connection between s and γ suggests that one may be evaluated from a measurement of the other.

It is worth pointing out that s is dependent on injection level in the same way as γ. Thus, the rate of surface recombination would be expected to go as the square of p_n when p_n becomes large compared to N_d. This is not usually observed in chemically treated samples which probably indicates that none of the simple models considered here may be applied to such surfaces.

Experimental Observations

The rather small values of s predicted by theory for a floating surface layer of opposite conductivity type should be directly measurable. A series of experiments which will be described in detail have been made to test this theory for the case of a very p-type layer on an n-type sample. The expected reduction in s is not obtained. It is by examination of these negative results that an opposing mechanism is revealed which contributes to our understanding of the floating barrier.

Lifetime Measurements

Diffusion Method: Surface recombination velocity is usually obtained by measuring the actual (often called "effective") lifetime of minority carriers in a sample of known volume lifetime and dimensions. Then s is obtained by computation for the specific geometry. For the case of a rectangular bar of cross-sectional dimensions B and C, Shockley gives the first order formula:[3]

$$1/\tau_m = 1/\tau_v + \nu_s, \tag{15}$$

where

$$\nu_s = 2s\left(\frac{1}{B}+\frac{1}{C}\right)$$

holds for small s.

Lifetime can be measured by the diffusion method in which the minority carrier density is measured as a function of distance from a line of light. If a thin bar (thickness$\ll$width) is used, the measured lifetime will be largely surface controlled, thus providing a simple measure of s on the large surfaces. If the thickness of the bar is W, then $s=W/2\,\tau_m$ when s is the same on both surfaces.

A sample (see Fig. 5) was used. One side of the bar carried a large indium alloy junction. This was the surface whose effective s was to be determined. The point contact and line of light were on the opposite side of the bar. Measurements could also be made on a region of the bar which did not have the floating junction layer. One might expect that the region including the junction, which, theory predicts, will have one side where $s\approx 0$, would show a longer lifetime by a factor of about 2, compared to the rest of the sample. This is because one-half of the surface sink is effectively removed. The situation is the same as if the bar had been in-

[12] W. Shockley, M. Sparks, and G. K. Teal, "P-N junction transistors," *Phys. Rev.*, vol. 83, pp. 151–162; July, 1951.

creased to twice its thickness, thereby decreasing γ_s by a factor two. Since the bar was known to have a volume lifetime in excess of several hundred microseconds, this would result in a doubled τ_m.

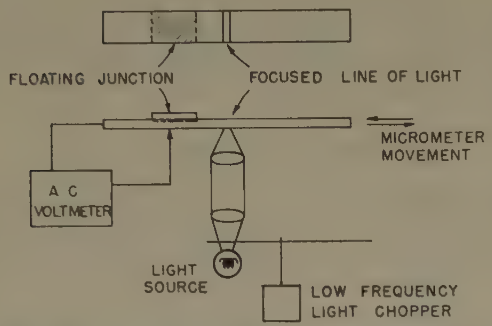


Fig. 5—Apparatus for measurement of lifetime by the diffusion method on a germanium bar carrying a floating alloy junction.

The results of such a measurement are shown in Fig. 6. The log of the open circuit probe voltage in arbitrary units is plotted against the distance between the probe and the light line. When this spacing is less than the thickness of the bar, the slope of the curve yields a lifetime of 90 μsec. This is about the same as the value measured at probe positions far removed from the

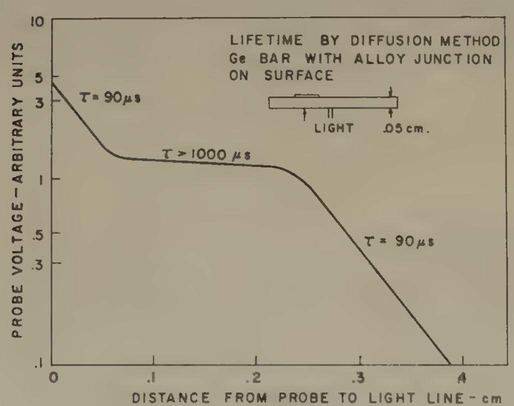


Fig. 6—Curve obtained by plotting probe voltage vs distance from probe to light line, using apparatus of Fig. 5.

floating alloy junction. As the light line is moved further than the bar thickness from the probe, the slope of the curve becomes practically zero, indicating an apparent lifetime of many thousands of microseconds. This is far in excess of the expected factor of 2. When the light line passes the edge of the floating p-layer, the curve resumes its original slope, which is characteristic, as before, of the lifetime far removed from the junction.

The apparent increase in lifetime cannot be explained on the basis of a reduced s on one surface. Additional experiments to be described were performed on the same bar in an effort to find the reason for the discrepancy.

Pulse Photo Conductivity: Another way to determine lifetime in the bar is to measure the time decay of excess conductivity after a pulse excitation of hole-electron pairs by a short flash of light.[9] In this measurement the conductivity variation is obtained from the voltage across a resistor in series with the sample and a bias battery. If the resistor is matched to the dark resistance of the sample, the light pulse is of low intensity so that $\Delta\sigma \ll \sigma$, and the field across the sample is sufficiently small such that the transit time of carriers due to the electric field is long compared to the decay of recombination, then

$$\frac{\Delta\sigma}{\sigma} = \text{const. } e^{-t/\tau}. \tag{16}$$

This method measures lifetime directly, instead of obtaining it through the diffusion relation $L = \sqrt{D\tau}$, as in the previous experiment.

The experimental arrangement is shown in Fig. 7. The light source is a spark discharge in air operated as a relaxation oscillator from a 5,000-volt power supply. When focused on the sample, the spark produces a line of light which was arranged perpendicular to the long axis of the sample. A micrometer screw enables the sample to be moved parallel to this axis so that the lifetime can be measured by the change in the voltage drop across a resistor connected in series with the sample and a bias battery. The measurement is made with an oscilloscope with a built-in delay line so that the entire trace can be studied. If the photoconductivity decays exponentially [as it should from (16)] the lifetime can be read directly on the oscilloscope face as the $1/e$ point.

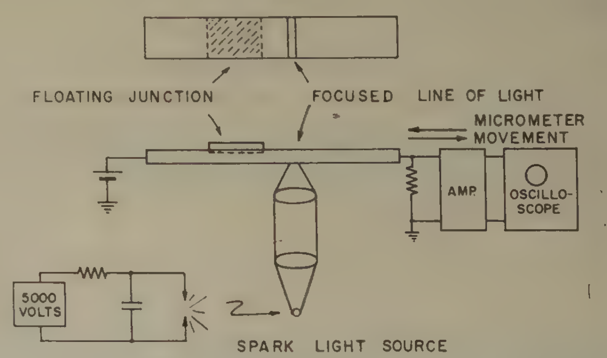


Fig. 7—Apparatus for measurement of lifetime and drift mobility by the drift method on a germanium bar carrying a floating junction.

At positions far removed from the floating junction, the decay time corresponded to 90 μsec, in agreement with the diffusion length measurement. In the floating junction region the decay departed from an exponential and could not possibly be construed as a doubling of the

lifetime. The detailed nature of this curve will be discussed later in connection with the drift-time measurement. For the present the conclusion is that the expected doubling of the decay time was not observed.

Diode Measurements: A measurement of the effective minority carrier lifetime in the base region of an alloy junction diode can be obtained by injecting minority carriers into the region with a pulse of forward current. The decay is then followed by observing the open circuit emitter voltage as a function of time.[8] The same measurement can be made in a transistor in which the collector is allowed to float electrically. If the base wafer is thin, the effective lifetime is a measure of s. Furthermore, most of the surface recombination will take place on the surface opposite the alloy junction, provided s is the same value there as at other surfaces. Now, if we substitute a large floating collector for the surface opposite the emitter, as in an alloy transistor, and if this surface actually has a very low value of s as predicted by the junction theory already given, one would expect a marked increase in the effective lifetime. Such measurements were made on a series of transistors and diodes of essentially identical emitter-base region geometry. Both diodes and transistors gave the same value of effective lifetime within experimental error. Thus, again, the expected reduction in s was not observed.

The Feed-In Feed-Out Effect

The negative results in the above experiments require examination and modification of the theory of surface recombination velocity at a floating junction. The most logical explanation appears to be connected with the fact that the p-type germanium on the surface is a good conductor (relatively) and hence, is an equipotential. Under conditions of an applied field within the n-type bar, or when a gradient of minority carrier density exists along the interface, the floating junction assumes the dual role of emitter and collector. While the net current across the junction is zero, this need not be true at every point. In fact, the effective s may be the same as for adjacent germanium surfaces. The p-region then acts as a translator of holes rather than as a low s interface. Some additional experiments which support this view will now be described.

Floating Potential Measurements: Indirect measurements indicate that the p-layer in an alloy junction has a resistivity of the order 0.001 ohm-cm. If an electric field is maintained in a bar which carries a floating junction, and if the bar has a resistivity of the order 1 ohm-cm, the p-layer can be considered as an equipotential surface. The situation is illustrated in Fig. 8. The layer will float at some potential intermediate between the potential V_b and V_a. Part of the junction is biased in the reverse direction, collecting thermally generated holes from the n-type bar, while the rest is biased in the forward direction, injecting holes back into the bar closer to the negative electrode. The net current across the junction is zero, since the p-layer is floating. No holes are lost in the process. Because the hole concentration in the p-type layer is much higher than the electron concentration in the n-type bar, most of the current crossing the junction in either direction will consist of holes. The hole currents will furthermore be small compared to the main electron current in the n-type bar. Hence it can be assumed that the electric field in the bar is not seriously disturbed by presence of the junction.

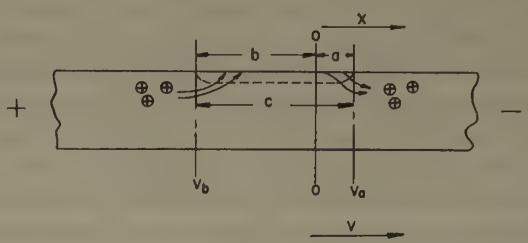


Fig. 8—Diagram for the calculation of the floating potential of the alloy junction.

The floating potential of the junction may be calculated by equating the integrated current for the forward biased region to that for the reverse biased region. One may take the position at which the potential in the germanium is equal to the p-layer potential as the zero of x and v. If the total potential drop $V_a - V_b$ is called V and the total length of the p region $a-b$ is called c, then $v=(x/c)V$. Then

$$-\int_{-b}^{0}(e^{qVx/kTc}-1)dx = \int_{0}^{a}(e^{qVx/kTc}-1)dx.$$

One can then solve for the floating potential V_f with respect to $V_a(V_f=(a/c)V)$:

$$V_f = \frac{kT}{q}\ln\left[\frac{qV/kT}{1-e^{-qV/kT}}\right]. \tag{17}$$

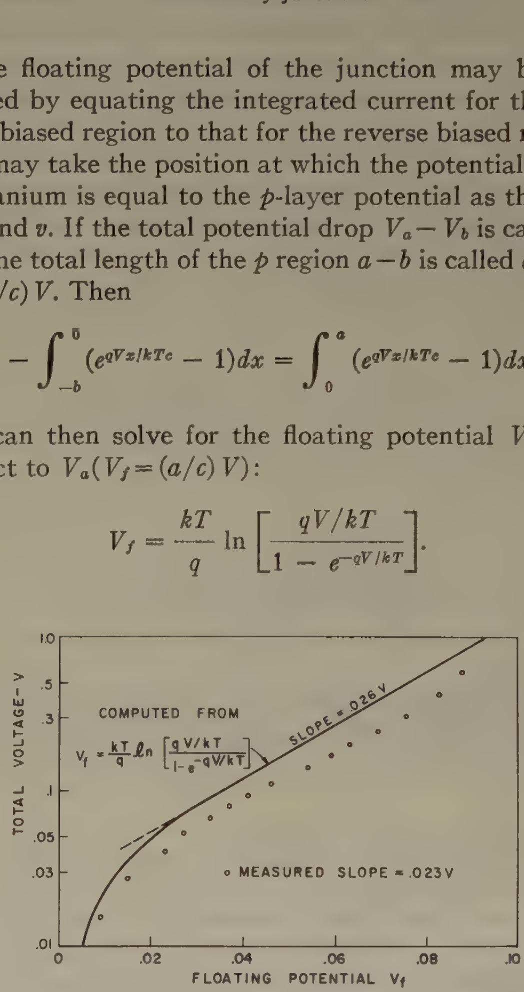


Fig. 9—Results of measurement of the floating potential comparison with (17). Measurement made at 300 degrees K.

Fig. 9 shows the result of a test of this equation. Both the floating potential and the total potential drop were measured by means of probes and a high-impedance millivoltmeter. Inasmuch as there are no adjustable constants in this equation, the agreement is considered

as satisfactory evidence of the feed-in feed-out phenomenon.

Mobility or Drift Time Measurements: The previous experiment suggests that holes can be translated towards a negative electrode through a p-type surface layer. It is presumed that this process occurs almost instantaneously, i.e., if a hole is fed into the reverse biased junction region another hole is immediately emitted at the forward biased region. This process occurs much faster ($\sim 10^{-11}$ sec) than ordinary minority carrier drift times ($\sim 10^{-5}$ sec). Thus, if the hole drift time in an electric field is measured on a bar carrying a floating junction, an artificially short drift time should be observed due to the bypassing action of the floating junction. The same pulse lifetime equipment described in connection with lifetime measurements was used to test this conjecture except that the field in the bar was increased to the point at which the drift time was shorter than the lifetime. The light pulse which acts as the hole source was focused at the center of the bar and the drift time measured for holes drifting first toward the end without the floating junction, and then, by reversal of the polarity of the electric field, for holes drifting through the part of the bar carrying the junction. Fig. 10 shows the two cases. From the dimensions of the bar and the length of the junction region, the drift time should have been halved for the second case. The measured ratio was 0.47.

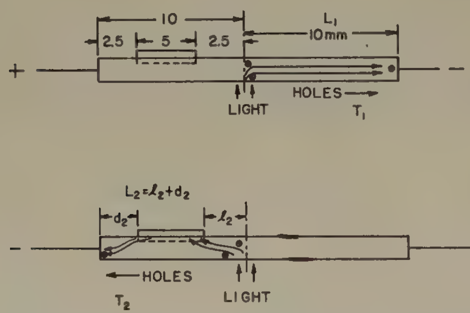


Fig. 10—Measurement of drift time in the germanium bar when (a) holes are confined to the bar volume and (b) when holes bypass the bar through the floating junction region. $T_2/T_1=0.47$; $L_2/L_1=0.50$.

Additional drift experiments using a light line movable along the bar have all confirmed the picture of instantaneous hole translation through the p-region. One point which was of special interest was the explanation of an unusual spike on the decay curve during pulse lifetime measurements in the vicinity of the floating junction. This is illustrated in Fig. 11. Initially (Region I), a sharp spike occurs, beginning immediately after the light injection pulse. Then the carriers decay exponentially and simultaneously drift in the electric field, as in Region II. Finally, carriers reach the end of the sample and the conductivity falls, as in Region III.

The pulse of light generates hole-electron pairs. In spite of the movement of the holes in an electric field, the hole charge remains neutralized by electrons in order to insure space charge neutrality. Since the translating action of the junction operates on holes only, the holes are re-emitted into the germanium without their accompanying neutralizing electrons. The spike is a consequence of redistribution of electrons which takes place in order to re-establish space charge neutrality. Part of this electron current comes up from ground through the load resistance, generating the spike voltage. The size of the spike depends on the resistance of the n-type germanium between the point of absorption and emission of the holes and the load resistance. The width depends on the capacitance in the external circuit.

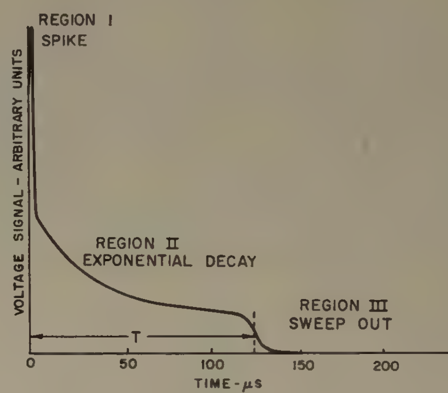


Fig. 11—Typical oscilloscope pattern during drift time measurement.

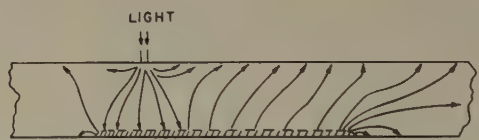


Fig. 12—Sketch of probable hole flow pattern during measurement of lifetime by diffusion method of Fig. 5.

Interpretation of Diffusion Measurements

The results of the diffusion measurement of surface recombination (See Diffusion Method, above) can be understood on the basis of hole translation. The hole flow pattern is of the type sketched in Fig. 12. Holes feed out from the source at the focused line of light. Some recombine at the surface adjacent to the source, but a larger number feed into the floating junction a distance W away. These are re-emitted about uniformly over the rest of the junction, providing a region along the upper surface in which the hole density is constant with distance along the bar. Thus the measured probe voltage becomes independent of distance after an initial dis-

tance W, as in Fig. 6, until the end of the floating junction is reached. Then there is no feed-in feed-out effect and the hole density falls off with distance in just the way to be expected for a surface controlled filament lifetime, i.e.,

$$\nu_s = \frac{2s}{W} \quad \text{or} \quad \tau_m = \frac{W}{2s}.$$

Interpretation of Diode Measurements

The same hole translation effect can take place in the measurement of effective lifetime in alloy transistor structures. After the emitter injection pulse is over, holes feed into the floating collector opposite the emitter, where the hole density is high. They immediately feed out again near the edge of the junction and so are lost to the adjacent surface. Hence this surface becomes the controlling sink, just as in the case of a diode structure without any collector. The fact that experimental agreement between diode and transistor effective lifetimes are about equal may be thus explained.

Conclusions

The fundamental reason for the failure of the junction analysis to predict the observed result is the assumption of a one-dimensional model. In this model the steady state hole and electron currents balance at every point along the boundary. In practice, that is for a three-dimensional case, the total currents balance, as required for steady state conditions, but they do not necessarily balance on a per unit area basis. If lateral gradients are not the same in the surface layer and in the bulk, circulating currents can exist, which destroy the effectiveness of the layer in reducing the surface recombination. Unfortunately, the requirement for low effective surface recombination is just that $\sigma_s \gg \sigma_b$, which implies that lateral conduction in the surface layer is large. This type of surface junction is therefore not suitable for reducing surface recombination in practical cases.

If it is not recognized, this effect can cause difficulty in some measurements. The measurement of lifetime in p-type germanium and in silicon by diffusion methods often yields results which are clearly too high. It is thought that this is due to the presence of layers of opposite conductivity type (inversion layer) on the surface, resulting from certain etches. While careful etching apparently removes this layer from n-type germanium, we have found no certain method of removing it from p-type germanium[13] or from n- and p-type silicon. The surface layer probably acts in much the same way as the floating junction in the above experiments; minority carriers from the base semiconductor bias the measuring probe through the inversion layer, thus making the probe voltage less dependent on the distance between probe and the source of hole-electron pairs. The fact that the inversion layer is on the same surface as the probe and source, rather than on the opposite side of a thin bar as in Figs. 5 and 6 does not materially effect the argument. The pulse method of Fig. 7 (See Pulse Photo Conductivity) is dependent only on the number of minority carriers actually within the bar and is independent of their special distribution, provided that the drift field is small enough to prevent sweep-out. Hence lifetime measurements on these materials are best made by the pulse drift method.

Under certain conditions, the interpretation of effective lifetime in completed transistors[8] can be affected by hole translation. If the collector does not penetrate deeply into the base wafer, the effective lifetime is simply related to the surface recombination velocity by $\tau_e = W/2s$, where W is the wafer thickness. If the collector does penetrate far into the wafer, the feed-out of holes from the edge of the collector to the adjacent free germanium surface effectively translates the recombining surface on the collector side closer to the recombining surface on the emitter side. Thus the effective thickness of the wafer is reduced. The measured effective lifetime is less in this case. When the transistor is in use as a device, however, the hole translation effect is not operative since the collector is biased in the reverse direction rather than floating as in the test measurement. The proper value of W can be determined empirically.

[13] Adsorption of H_2O vapor plays a part in creating the inversion layer on p-type germanium. See H. Christiansen, "Surface conduction channel phenomena in germanium," Proc. I.R.E., vol. 42, pp. 1371–1376; September, 1954; also A. L. McWhorter and R. H. Kingston, *ibid.*, pp. 1376–1380.

A Chart for Analyzing Transmission-Line Filters from Input Impedance Characteristics*

HARVEL N. DAWIRS†, ASSOCIATE, IRE

Summary—**Filter calculations become difficult when network elements consist of transmission-line sections, since transcendental equations are involved. It is the purpose of this paper to describe the application of familiar impedance methods and Smith chart[1,2] techniques which simplify many of these calculations. A chart is developed by means of which the most important characteristics of a filter may be read directly from a conventional input impedance curve plotted on a Smith chart. The principles involved in these methods are equally valid for all lossless filters consisting of identical and symmetrical sections, but are particularly well-suited for use with transmission-line circuits.**

Introduction

It is often necessary to construct filters in the frequency range where transmission-line circuits are used. In this range the elements of the filters must be sections of transmission line. The design of such filters is difficult because the usual design equations become transcendental and are difficult to solve. It is common practice, however, to manipulate such expressions arising in connection with transmission-line circuits by means of the Smith impedance chart.[1,2] It is the purpose of this paper to show how these Smith chart techniques may be used to facilitate many important calculations encountered in the design of lossless transmission-line filters which consist of identical and symmetrical sections.

Since only lossless filters consisting of identical and symmetrical sections are considered, the input impedance of the filter is given by the expression[3]

$$z_c \frac{z_l \cosh \gamma_n + z_c \sinh \gamma_n}{z_l \sinh \gamma_n + z_c \cosh \gamma_n}, \tag{1}$$

where

z_c is the characteristic impedance of the filter,

z_l is the impedance of the terminating load,

$\gamma_n = \alpha_n + j\beta_n$ is the propagation constant of the filter,

and

n is the number of sections in the filter.

This expression can be put into the form

$$z_n = \frac{z_0 + \tanh \gamma_n}{1 + z_0 \tanh \gamma_n}, \tag{2}$$

where

$z_n = r_n + jx_n$ is the input impedance of the filter normalized to z_c,

and

$$z_0 = r_0 + jx_0 = z_l/z_c. \tag{3}$$

In all further discussion let z_l be an arbitrary (but fixed) real impedance and define:

$$Z_n = R_n + jX_n = z_n/z_0, \tag{4}$$

and

$$Z_c = z_c/z_l. \tag{5}$$

Note that Z_n and Z_c are, respectively, the input impedance and the characteristic impedance of the filter, both normalized to z_l and that $Z_c = 1/z_0$. With these definitions the expression

$$Z_c = \sqrt{\frac{R_n^2 + X_n^2 - R_n}{R_n - 1}} \tag{6}$$

follows from (2) for both the pass and rejection bands.

Since, for transmission-line circuits Z_n is easily obtained by well-known procedures, (6) provides a convenient means of determining the characteristic impedance of a transmission line filter.

Significant Impedance Relations on the Smith Chart

Now consider the significance of (6) in relation to the Smith chart and to the input impedances of a filter. (It is assumed throughout the remainder of this paper that all filter input impedances are obtained with the filter terminated in z_l and that these are normalized to z_l and plotted as points or a curve on the Smith chart.)

Eq. (6) indicates that cutoff occurs when $R_n = 1$ ($Z_c = \infty$), or when $R_n = R_n^2 + X_n^2$ ($Z_c = 0$). These relations are equations of two easily identified circles on the Smith chart which will be called "CUT-OFF CIRCLES." (See Fig. 1, facing page.) At a cut-off frequency the input impedance of a filter will fall on one of these circles, and conversely, the cut-off circles will intersect the input impedance curve of a filter at any cut-off frequency.

* Original manuscript received by the IRE, June 21, 1954; revised manuscript received, January 13, 1955. This work was supported by a contract between Wright Air Dev. Center, and the Ohio State Univ. Res. Found.

† Antenna Lab., Dept. Elect. Engrg., Ohio State Univ., Columbus, Ohio.

[1] P. H. Smith, "A transmission line calculator," *Electronics*, vol. 12, pp. 29–31; January, 1939.

[2] P. H. Smith, "An improved transmission line calculator," *Electronics*, vol. 17, pp. 130–133, 318–325; January, 1944.

[3] J. J. Karakash, "Transmission Lines and Filter Networks," The Macmillan Company, New York, N. Y., p. 169; 1950.

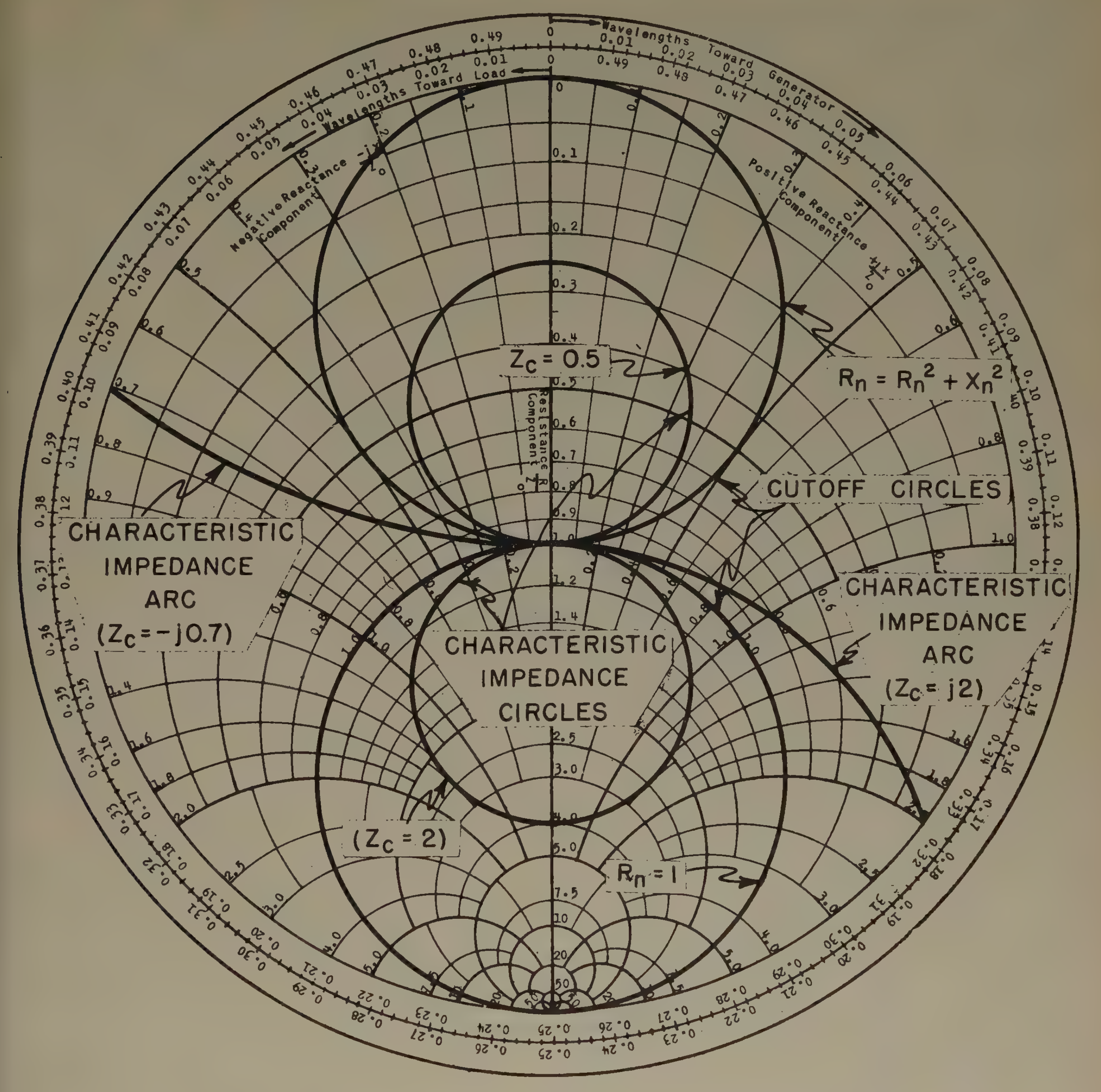


Fig. 1

Further consideration of (6) shows that Z_c is real whenever Z_n lies within one of the cut-off circles and is imaginary for all Z_n outside of the cut-off circles. Thus the cut-off frequencies may be determined and the pass and rejection bands identified directly from the input impedance curve of a filter by means of the cut-off circles.

For a fixed value of Z_c in the pass band, (Z_c real and positive), (6) is the equation of a circle on the Smith chart, which is tangent to the cut-off circles at the center of the chart and lies wholly inside one of them as shown in Fig. 1. There is one of these circles, which will be called a "CHARACTERISTIC IMPEDANCE CIRCLE," associated with each positive real value of Z_c. This circle will intersect the real axis at the point

$$R_n = Z_c^2, \tag{7}$$

as determined by setting $X_n = 0$ in (6). Eq. (6) indicates that the input impedance Z_n of a filter at any given frequency in the pass band must fall on the impedance

circle corresponding to the characteristic impedance of the filter at that frequency. Conversely, a characteristic impedance circle constructed on a Smith chart [this may be done quite easily using (7)], will intersect the input impedance curve of a filter at the frequencies for which the characteristic impedance of the filter is equal to the value associated with the intersecting circle.

Note that if the input impedance of a filter is known at any particular frequency, the characteristic impedance of the filter at that frequency may be found by constructing the unique characteristic impedance circle through the known impedance point and calculating Z_c[by (7)] from the point at which the circle intersects the real axis.

A number of typical characteristic impedance circles may be constructed as auxiliary co-ordinates on a Smith chart and used to determine characteristic impedances of a filter, in its pass bands, directly from an input impedance curve of the filter plotted on the same chart.

Now for a fixed value of Z_c in the rejection band (Z_c imaginary), (6) is the equation of an arc on the Smith chart which is tangent to the cut-off circles (and also to the characteristic impedance circles), at the center (see Fig. 1), and terminates on the rim of the chart. There is a unique arc, which we shall call a, "CHARACTERISTIC IMPEDANCE ARC," associated with each imaginary value of Z_c, terminating at the point

$$X_n = -jZ_c \tag{8}$$

on the rim of the chart (since $Z_c = \sqrt{-X_n^2} = jX_n$ when $R_n = 0$). Thus, (6) implies that the input impedance of a filter at any given frequency in the rejection band must fall on the impedance arc which corresponds to the characteristic impedance of the filter at that frequency. Hence, if the input impedance of the filter is known at any given frequency in the rejection band, the characteristic impedance of the filter at that frequency may be determined by constructing the unique characteristic impedance arc through the known impedance point (by means of a compass), and noting the point at which it intersects the chart rim. The value of Z_c follows by (8).

Conversely (6) implies that a characteristic impedance arc will intersect the input impedance curve of a filter at a frequency for which the characteristic impedance of the filter is equal to that associated with the intersecting arc. A number of typical characteristic impedance arcs may be constructed as auxiliary co-ordinates on a Smith chart [(8) may be conveniently used for this purpose], and used to determine the characteristic impedances of the filter at rejection band frequencies by means of the intersections of the arcs with the input impedance curve of the filter.

Filter Analysis Chart

Fig. 2, facing page, is a chart, based upon principles just considered, which may be used to determine many important properties of filters directly from a plot of their input impedances. The co-ordinates of this chart are normalized characteristic impedance and propagation constant. The characteristic impedance co-ordinates consist of the cut-off circles, the characteristic impedance circles and the characteristic impedance arcs discussed previously. The propagation constant co-ordinates are obtained by calculating typical values [by means of (2)] and plotting these on the Smith chart. Note that the co-ordinates of the filter analysis chart are considered to be superimposed upon a Smith chart even though the usual impedance co-ordinates are not shown. Desired impedance points are located by means of a calibrated cursor and the scale around the outside rim.

In the pass band the propagation constant, which is imaginary and hence consists only of the phase constant, is scaled in wavelengths for convenience in use with transmission lines. In the rejection band the propagation constant, which is real and hence consists only of the attenuation constant, is scaled in decibels.

To make use of the chart in analyzing a filter, the filter is terminated in a real impedance z_l and the input impedance measured as a function of frequency over the range of interest. These impedances are then normalized to z_l, and plotted on the analysis chart in the same manner as on a Smith chart. (See Fig. 3, page 440). Since these measurements are usually made and plotted in terms of phase shift and voltage standing-wave ratio (or voltage-reflection coefficient), they may be plotted directly on the analysis chart just as conveniently as on the Smith chart itself if z_l is chosen to be equal to the characteristic impedance of the slotted line (or directional coupler), used in making the measurements.

Now the cut-off frequencies may be determined and the rejection and pass bands identified by means of the cut-off circles as described previously. The normalized characteristic impedance and the propagation constant at any frequency may be read directly from the co-ordinates of the corresponding input impedance point. The characteristic impedance read from the co-ordinates is normalized to z_l. (That is $Z_c = z_c/z_l$.)

In addition the attenuation of the filter (which in this case is equal to its reflection loss), at any given frequency may be determined by reading the reflection loss of the corresponding input impedance point by means of a calibrated cursor,[2] or may be calculated by means of the formula[2]

$$\text{db} = 10 \log (1 - |\rho|^2), \tag{9}$$

where ρ is the reflection coefficient (either current or voltage) of the input impedance point.

Note that:

1. The input impedance curve is obtained by routine procedures, using standard equipment and techniques;
2. Only one measurement is required at any one fre-

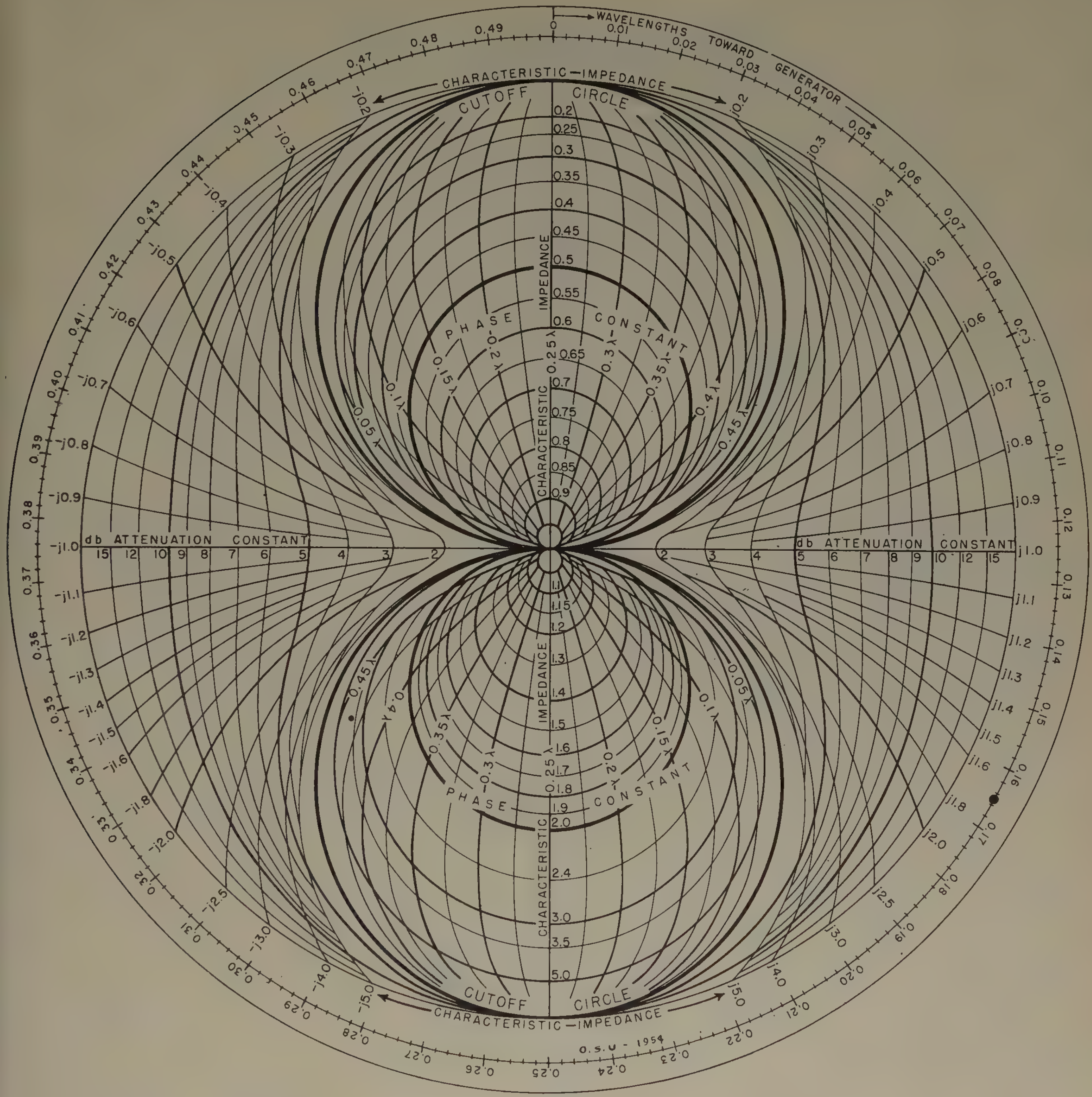


Fig. 2

quency (as against two required for the open- and short-circuit method); and

3. Calculations are eliminated by reading values directly from the chart co-ordinates (or a cursor).

The properties obtained by such procedures are:

1. Cut-off frequencies;
2. Pass bands;
3. Rejection bands;
4. Characteristic impedances;
5. Propagation constants; and
6. Attenuation.

Further Applications of the Chart[4]

If a proposed filter is to be analyzed from calculated data, the input impedance of only a single section is necessary, since the cut-off frequencies, the rejection and pass bands, and the characteristic impedances of a filter are the same as for the component sections. Hence all these properties may be determined directly from

[4] H. N. Dawirs and E. K. Damon, "Application of the Ohio State University Filter Analysis Chart," presented at *NEC*, Chicago, Ill.; October 5, 1954.

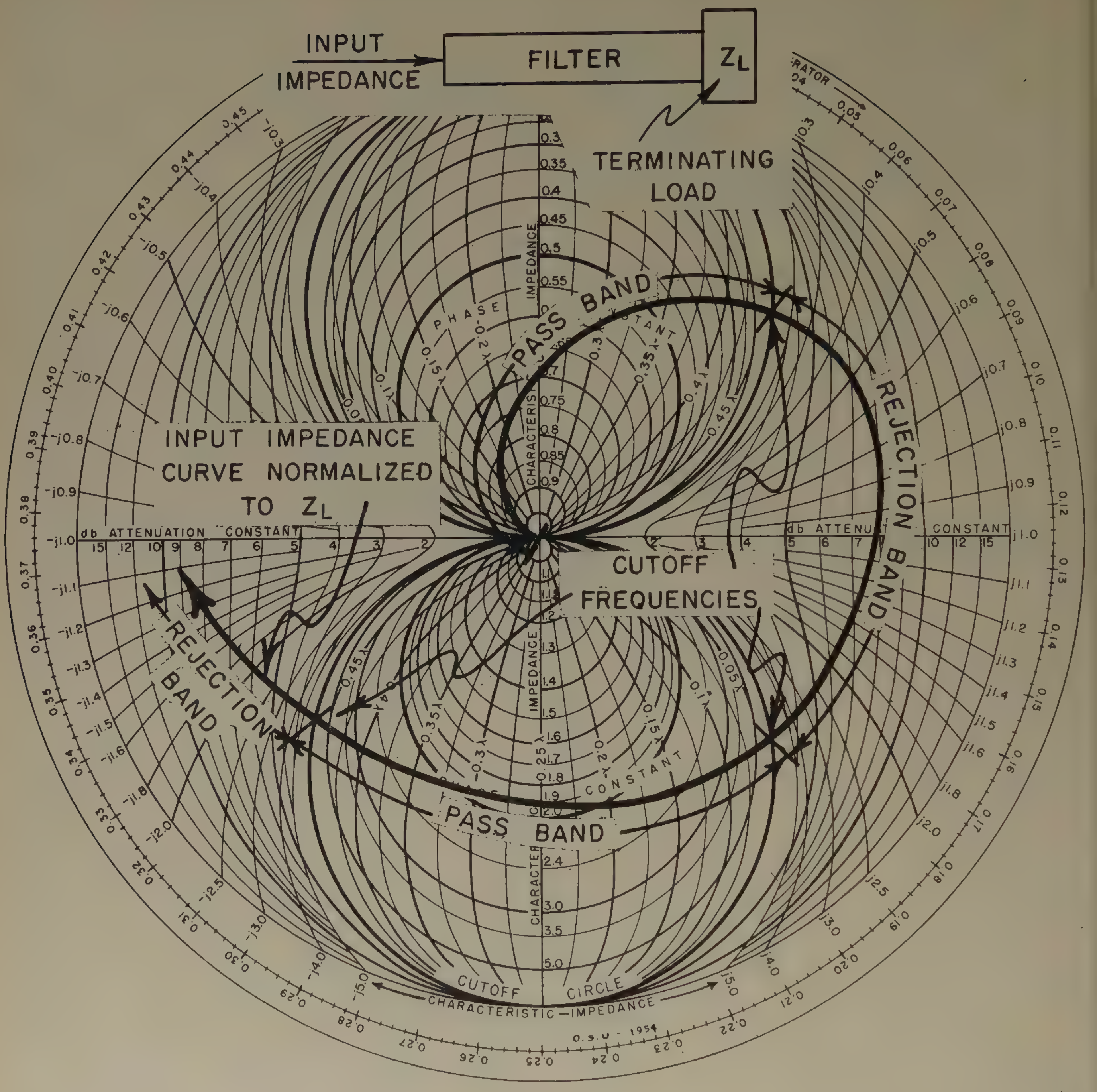


Fig. 3

the input impedance curve of a single section. The propagation constant $\gamma_n = n\gamma_1$, of an n-section filter is easily determined from the propagation constant γ_1 of a single section as read from the chart.

The value of the terminating impedance may often be chosen to simplify the calculation of the input impedance of the single section. Consider, for example, a filter section consisting of a reactance located at the midpoint of a transformer section of transmission line as shown in Fig. 4. If Z_l is chosen to be equal to Z_0, the normalized impedance looking towards the reactance gap at the center will be simply $1+jX$, where the normalized reactance of the series stub is determined by usual Smith

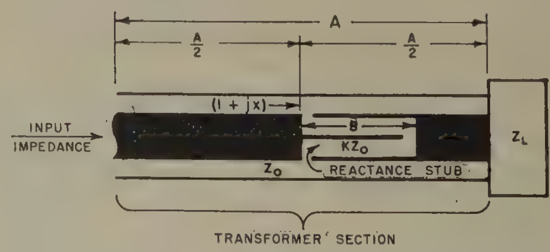


Fig. 4

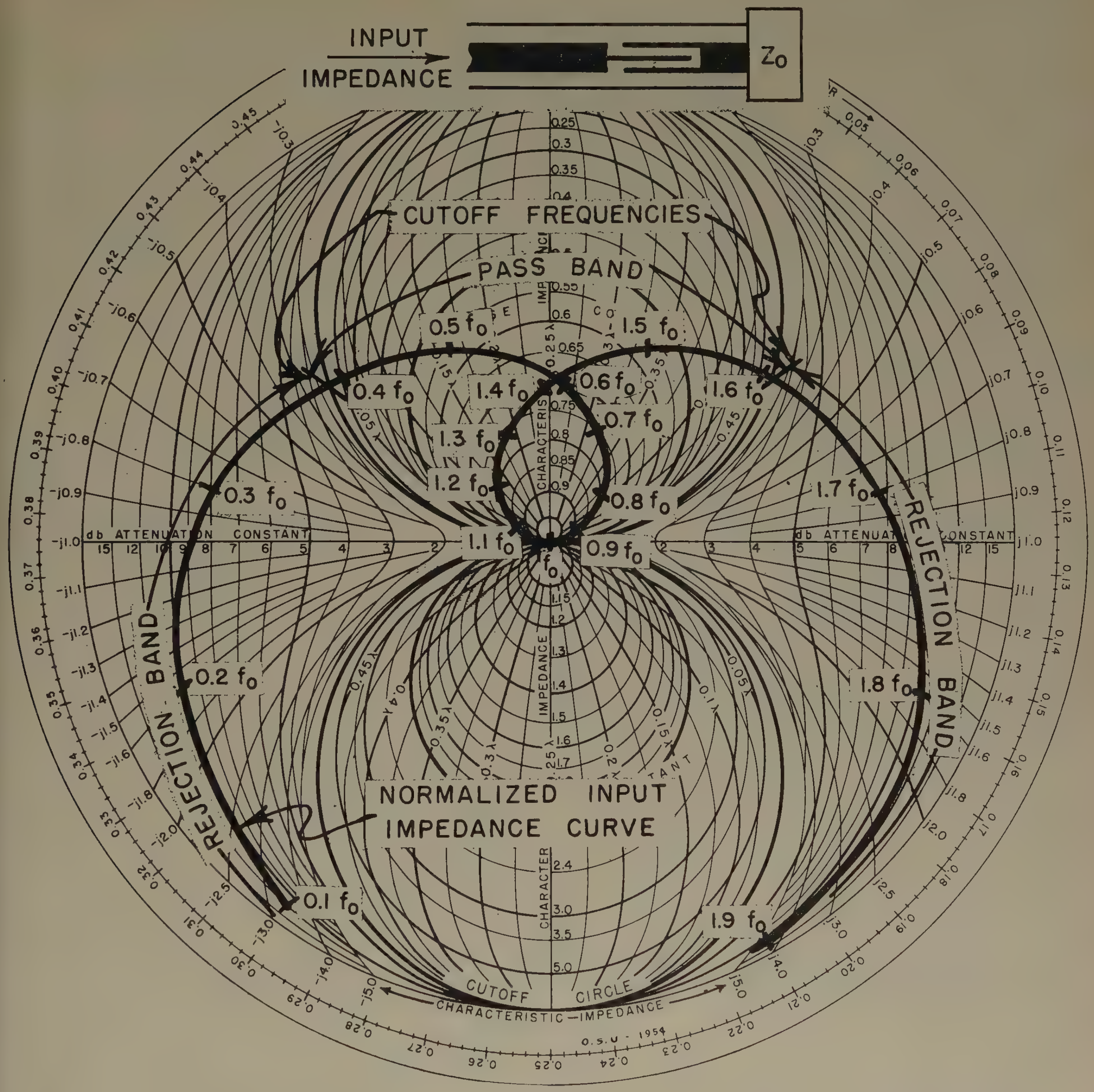


Fig. 5

chart methods. The impedance $1+jX$ is then transformed through the remaining half of the transformer section (a simple task on the Smith chart) to obtain the normalized input impedance curve of the section. Fig. 5 shows a typical input impedance curve for a filter section of this type.

It is interesting to observe the effect on the input impedance of a filter as a result of adding sections. Since, at any given frequency, the characteristic impedance of a filter is independent of the number of sections, the input impedance point Z_n, must always lie on the impedance co-ordinate corresponding to the characteristic impedance of the filter at that frequency. However the propagation constant of the filter at a given frequency ($\gamma_n = n\gamma_1$), is a function of the number of sections.

At a particular frequency in the pass band, for example, the input impedance point is confined to a spe-

cific characteristic impedance circle, but progresses around and around this circle as sections are added. At other frequencies in the pass band the corresponding input impedance points progress around other impedance circles and at different rates as sections are added. Note that as an input impedance point progresses around its impedance circle the attenuation (or reflection loss), oscillates between zero when the impedance point is at the center of the chart, and a maximum when the point is at $R=\sqrt{Z_c}$. The maximum attenuation at each frequency in the pass band can be determined from the corresponding impedance circle by means of a cursor or (9) and plotted as shown in Fig. 6. The maximum attenuation curve in Fig. 6 was obtained from the input impedance curve in Fig. 5 for the filter section shown in Fig. 4. This curve is characteristic of a filter section and is a property of a filter composed of such sections, which is independent of the number of sections involved. The attenuation of a filter will oscillate between zero and the maximum attenuation curve in the pass band as a function of both the frequency and the number of sections, but can never exceed the values indicated by the curve.

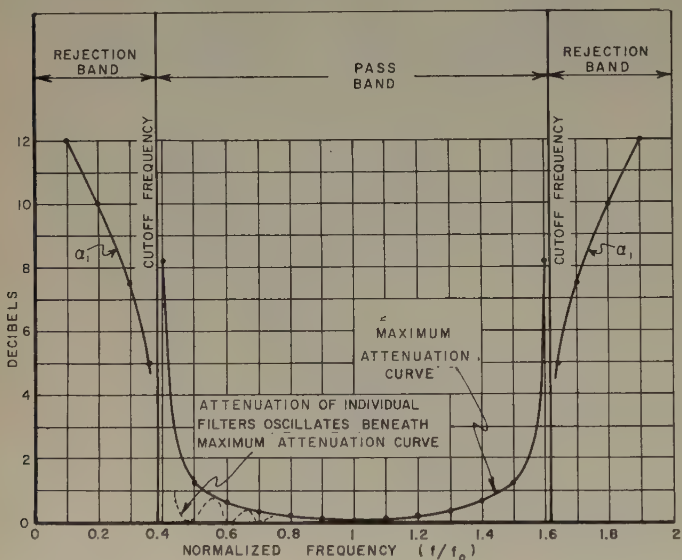


Fig. 6

At any particular frequency in the rejection band the input impedance point must remain on the corresponding characteristic impedance arc, but progresses outward along it as sections are added, approaching the rim as a limit. Thus the reflection loss, and hence the attenuation of the filter increases as sections are added. In fact the db attenuation of the filter at a given frequency in the rejection band becomes nearly a linear function of the number of sections. That is

$$\text{db} \cong [A + (n - k)\alpha_1], \tag{10}$$

where A is the attenuation due to the first k sections. This becomes more nearly true as k becomes large but may often be used for making useful approximations, even when k is small. For example

$$\text{db} \cong (n - 1)\alpha_1 \tag{11}$$

is usually a reasonable estimate of attenuation for practical purposes but does require a certain amount of judgment in its use.

A chart, such as is shown in Fig. 6, which may be used to evaluate the general performance of a filter section and to determine its suitability for given filter applications, may be constructed using the filter analysis chart. The cut-off frequencies of the section are indicated, the attenuation constant α_1 is plotted over the rejection band and the maximum attenuation curve discussed previously is plotted over the pass band. The cut-off frequencies and the rejection and pass band frequencies of a filter constructed of these sections are shown, the range over which the pass band attenuation of such a filter will be less than a specified value (regardless of the number of sections) may be determined from the maximum attenuation curve, and the number of sections required to obtain the desired attenuation at specified frequencies or over given ranges in the rejection band may be estimated from the curve of α_1. Thus, such a chart is of considerable practical value in the design of transmission-line filters.

In addition to the above analysis and design application, the filter analysis chart may be used as an aid in the synthesis of some types of filters. As an example of this consider the filter section previously discussed and shown in Fig. 4. Examination of the input impedance curve shown in Fig. 5 indicates that the characteristic impedance of the filter will be equal to the characteristic impedance of the transformer section at a frequency which we shall call f_0. This is the frequency for which the length, B, of the reactance stub is a quarter of a wavelength long. Hence the stub appears as a short circuit across the reactance gap and the filter section consists only of the transformer section of transmission line. Thus the characteristic impedance of the transformer section and the length of the reactance stub can be chosen so that the filter will match into a given load at a given frequency.

Further examination of the input impedance curve shown in Fig. 5 indicates that there exists a cut-off frequency, which we shall call f_c, which is below f_0. Now the filter analysis chart may be used to synthesize a filter section of the type being considered which will match into a given load at a specified frequency and will have a given cut-off frequency f_c. To do so the characteristic impedance of the transformer section is chosen to be equal to the impedance of the given load and the length B of the reactance stub is chosen to be a quarter of a wavelength long at the specified frequency. Now to obtain the desired cut-off frequency it is necessary to determine the characteristic impedance of the reactance stub and the length of the transformer. Either of these may be chosen and the other determined. A choice of

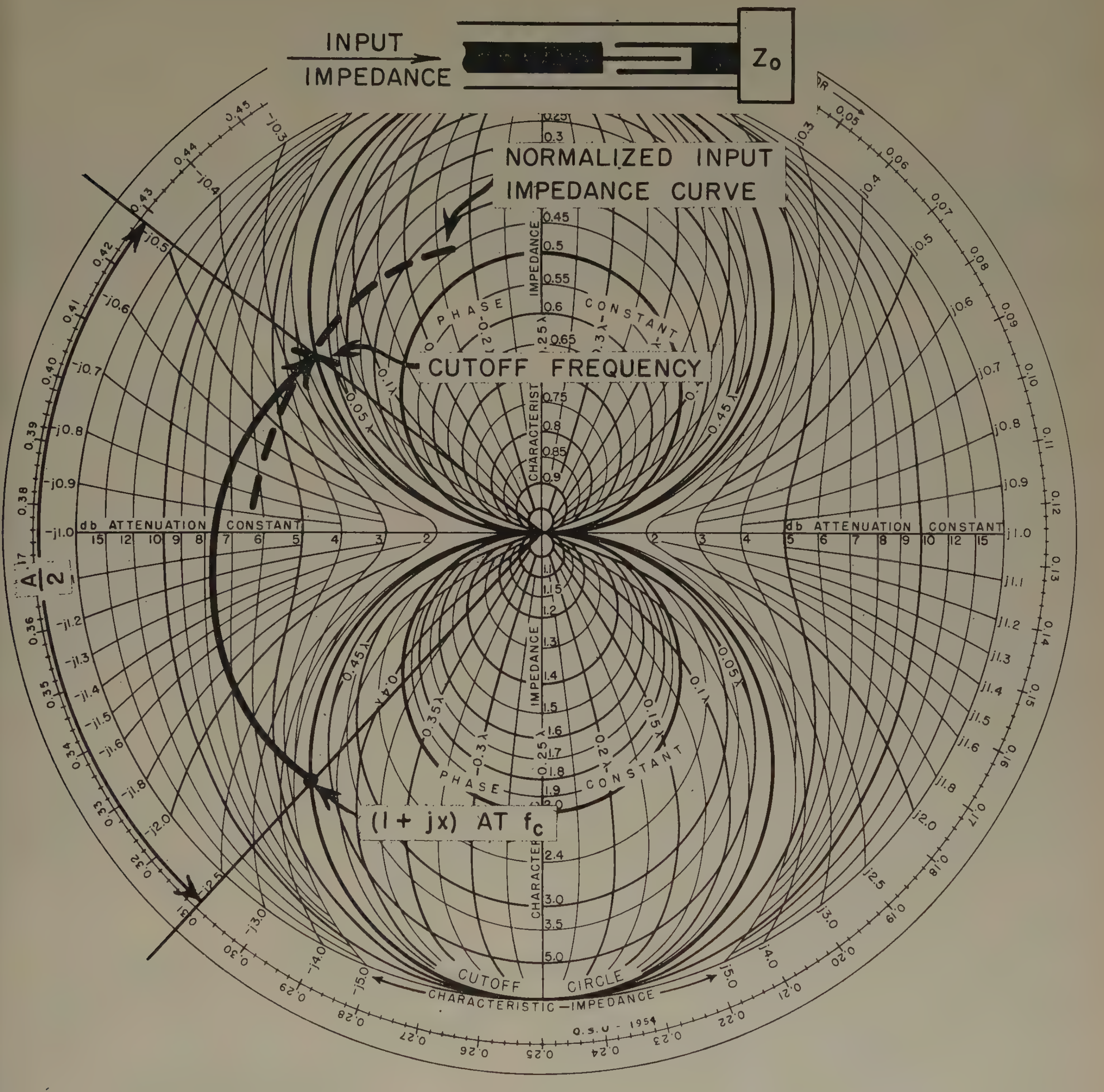


Fig. 7

a convenient value for the characteristic impedance of the reactance stub is best as an arbitrary choice of the transformer length may result in an impractical value for the characteristic impedance of the stub.

With the length and characteristic impedance of the series stub established, the input reactance, x, of the stub may be determined at the desired cut-off frequency, f_c, by ordinary Smith chart methods. It is now only necessary to determine the length of transmission line required to transform the resulting impedance point, $(1+jX)$, to the nearest cut-off circle as shown in Fig. 7. This is $A/2$ or one-half the total required length of the transformer section at f_c. Thus all of the values required to properly construct the filter section have been determined.

Acknowledgment

It would be difficult to name all of those who assisted in the preparation of this paper. However, of particular importance was the co-operation of L. A. Kail in drawing the filter analysis chart itself as well as a number of the other illustrations.

Concerning the Noise Figure of a Backward-Wave Amplifier*

T. E. EVERHART†

Summary—**The noise figure of a traveling-wave amplifier has been derived as a function of circuit loss and space charge. The minimum-obtainable noise figure of the backward-wave amplifier is shown to be the same as the minimum-obtainable noise figure of the forward-wave amplifier, i.e., about 6 db. The noise figure of an ordinary backward-wave amplifier has been measured as a function of gain. The calculated noise figure checks well with the measured values.**

NOISE, as related to thermionic vacuum tubes, is caused by random motion of the electrons. This random motion may be attributed to thermal kinetic energy, random emission from thermionic cathodes, random division among the various electrodes in a vacuum tube, or various other causes. The minimum input signal which can be detected by a given tube is determined by the noise of that tube; the higher the noise, the larger the minimum detectable input signal must be. For this reason, it is desirable to predict the noise one might expect from a certain type of amplifier, to devise means to reduce this noise, and to establish a minimum noise level which might be attained with a given type of tube. The noise properties of the forward-wave traveling-wave tube amplifier have been analyzed by several persons;[1-3] we shall examine the noise properties of a backward-wave traveling-wave tube amplifier, using the results of these previous analyses where they are applicable.

The backward-wave amplifier is a relatively new beam-type amplifier. It is closely related to the backward-wave oscillator,[4,5] which is a voltage-tunable, regenerative traveling-wave tube oscillator. In both amplifier and oscillator, the electron beam interacts with a space-harmonic of the circuit whose group and phase velocities are oppositely directed. The phase velocity is toward the collector (in the same direction as the electron velocities), while the group velocity, and hence energy flow, is toward the electron gun end of the circuit. When the beam current is low, and the electron velocity is very nearly the circuit velocity at the frequency in question, a signal impressed at the collector end of the circuit will appear amplified at the gun end of the circuit. If the beam current is raised, it will reach a discrete value at which the backward-wave amplifier becomes a backward-wave oscillator. At currents slightly below the start oscillation current, a very high, narrow-band electronic gain is obtained, the center frequency of which is voltage tunable. Such an amplifier has several applications; it could be used as a narrow-band detector, an electronically tuned filter, or in numerous microwave devices. A knowledge of the noise figure of this amplifier is both interesting and important. We shall derive a general expression for the noise figure, including the effects of space charge and circuit loss.

Noise figure is defined as the noise power output of an amplifier whose input is matched to its characteristic impedance divided by the output of a noiseless amplifier whose input is similarly matched. The output of the latter is simply power gain times the noise power available from the characteristic impedance, or, symbolically, $P_t = GkTB$. (Because the notation in this paper will be familiar to many workers in the field, the definition of symbols used is omitted from the text. These definitions are presented at the end of the paper.)

Fig. 1 gives a schematic picture of a backward-wave amplifier. In analyzing the interaction space, we shall assume a circuit input voltage at $z=l$, and an alternating velocity and current noise modulation in the beam at $z=0$. The electrons are constrained to move only in the z direction by an infinite axial magnetic field.

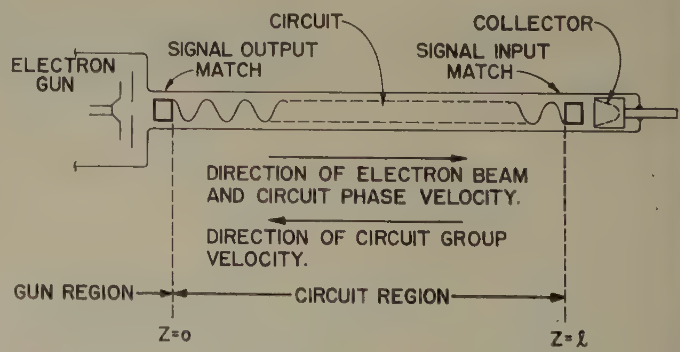


Fig. 1—Schematic diagram of a helix-type backward wave amplifier.

Analysis of Circuit Region

We assume that the reader is familiar with Pierce's analysis of the traveling-wave tube.[6] Johnson has modified this analysis to describe backward-wave interac-

* Original manuscript received by the IRE, November 10, 1954; revised manuscript received January 10, 1955. Taken from Hughes Report No. 40-31-00-3, October 15, 1954.

† Res. and Dev. Labs., Hughes Aircraft Co., Culver City, Calif.

[1] J. R. Pierce, "Traveling-Wave Tubes," D. Van Nostrand Co., Inc., New York, N. Y., Ch. 10; 1950.

[2] D. A. Watkins, "Noise Reduction in Beam Type Amplifiers," Electronics Research Laboratory, Stanford University, Technical Report No. 31, Stanford, California; March 15, 1951.

[3] S. Bloom and R. W. Peter, "A minimum noise figure for the traveling-wave tube," *RCA Rev.*, vol. 15, pp. 252–267; June, 1954.

[4] R. Kompfner and N. T. Williams, "Backward-wave tubes," Proc. I.R.E., vol. 41, pp. 1602–1611; November, 1953.

[5] H. R. Johnson, "Backward-Wave Oscillators," Hughes Aircraft Company Technical Memorandum No. 361; May, 1954.

[6] Pierce, *op. cit.*, ch. 2, 7–9.

tion.[7] He defines Pierce's impedance parameter K as follows:

$$K = -\frac{E_z^2}{2\beta^2 P}. \tag{1}$$

K is positive because P is negative for a backward-wave interaction. Pierce's loss parameter d is defined so that $d>0$ corresponds to circuit attenuation for a backward wave. The other parameters of Pierce are defined as usual. This analysis yields a small C determinantal equation

$$-\delta^2 = \frac{1}{-b - jd + j\delta} + 4QC. \tag{2}$$

Realizing that the relation between the partial "total voltage" V_i, and the partial "circuit voltage" V_{ci} of Pierce is as follows,

$$\frac{V_{ci}}{V_i} = 1 + \frac{4QC}{\delta_i^2} \quad (i = 1, 2, 3), \tag{3}$$

and writing the equations relating partial circuit voltages to total circuit voltage, total alternating beam velocity, and total alternating current, we have the following expressions. (Unless otherwise indicated, all voltages are taken at axial position $z=0$.)

$$V_{c1} + V_{c2} + V_{c3} = V_c \tag{4}$$

$$\frac{V_{c1}}{\delta_1^2 + 4QC} + \frac{V_{c2}}{\delta_2^2 + 4QC} + \frac{V_{c3}}{\delta_3^2 + 4QC} = i\left(-\frac{2V_0C^2}{I_0}\right) \tag{5}$$

$$\frac{\delta_1 V_{c1}}{\delta_1^2 + 4QC} + \frac{\delta_2 V_{c2}}{\delta_2^2 + 4QC} + \frac{\delta_3 V_{c3}}{\delta_3^2 + 4QC} = v\left(\frac{ju_0C}{\eta}\right). \tag{6}$$

If (4), (5), and (6) are solved for V_{c1}, it is found that

$$V_{c1} = \frac{-V_c[(\delta_1^2 + 4QC)(\delta_2 - \delta_3)] + \left(j\frac{u_0C}{\eta}\right)v[(\delta_1^2 + 4QC)(\delta_2^2 - \delta_3^2)]}{(\delta_1 - \delta_2)(\delta_2 - \delta_3)(\delta_3 - \delta_1)} + \frac{\left(-\frac{2V_0C^2}{I_0}\right)i[\delta_2(\delta_3^2 + 4QC) - \delta_3(\delta_2^2 + 4QC)](\delta_1^2 + 4QC)}{(\delta_1 - \delta_2)(\delta_2 - \delta_3)(\delta_3 - \delta_1)}. \tag{7}$$

V_{c2} and V_{c3} are cyclic permutations of V_{c1}. Now $V_1(l) = V_1 \exp(2\pi CN\delta_1)$, and since V_1 and V_{c1} are related by a constant independent of axial position, z, we have $V_{c1}(l) = V_{c1} \exp 2\pi CN\delta_1$. Adding $V_{c1}(l)$, $V_{c2}(l)$, and $V_{c3}(l)$, and solving for V_c results in the following expression:

$$V_c = -V_c(l)\frac{\xi(\delta)}{D(\delta, QC)} + \left(j\frac{u_0C}{\eta}\right)v\frac{\tau(\delta, QC)}{D(\delta, QC)} + \left(-\frac{2V_0C^2}{I_0}\right)i\frac{\phi(\delta, QC)}{D(\delta, QC)} \tag{8}$$

where

$$\xi(\delta) = (\delta_1 - \delta_2)(\delta_2 - \delta_3)(\delta_3 - \delta_1) \tag{8a}$$

$$\tau(\delta, QC) = (\delta_1^2 + 4QC)(\delta_2^2 - \delta_3^2)\exp 2\pi CN\delta_1 + \text{cyclic permutation} + \text{cyclic permutation} \tag{8b}$$

$$\phi(\delta, QC) = (\delta_1^2 + 4QC)[\delta_2(\delta_3^2 + 4QC) - \delta_3(\delta_2^2 + 4QC)] \cdot \exp 2\pi CN\delta_1 + \text{cyclic permutation} + \text{cyclic permutation} \tag{8c}$$

$$D(\delta, QC) = (\delta_2 - \delta_3)(\delta_1^2 + 4QC)\exp 2\pi CN\delta_1 + \text{cyclic permutation} + \text{cyclic permutation.} \tag{8d}$$

Eq. (8) expresses the voltage appearing on the circuit at $z=0$ (the circuit output) as a function of the voltage appearing on the circuit at $z=l$ (the circuit input) and the beam velocity and current modulation at $z=0$. The δ's appearing in the above equation are functions of b, d, and QC. The latter two quantities, d and QC, do not vary if the loss and beam current of a given tube are held constant. On the other hand, b is varied merely by adjusting the beam voltage, holding the frequency constant. Johnson has calculated the δ's and the CN for which oscillation begins for given values of d and QC.[8] This is done by setting D above equal to zero, and solving for CN, using the expression relating δ to b, d, and QC. It is logical to assume that the b of maximum gain for the backward-wave amplifier is the same as the b of start oscillation. This is very nearly true if CN is within 5 to 10 per cent of $(CN)_s$. This assumption restricts the range of validity of the numerical results presented here. If exact results are desired, the roots of the determinantal equation may be found for various b's, and these roots, together with the desired CN, may be substituted into (8). We therefore substitute the δ's found by Johnson in (8). CN is quickly determined by the relation

$$CN = (CN)_s\left(\frac{I_0}{I_{0s}}\right)^{1/3} \tag{9}$$

where I_{0s} is the current at which the tube starts to oscillate and $(CN)_s$ is tabulated by Johnson.[5]

We must now transfer circuit voltage into circuit power. Since the thermal noise is not correlated to the beam noise, we must add the two as powers. To avoid

[7] Johnson, *op. cit.*, pp. 2–3.

[8] *Ibid.*, pp. 5, 7.

confusion, all voltages, currents, and velocities from this point will be taken as root-mean-square quantities. Keeping this in mind, and using the definition of C at the circuit entrance,

$$C^3 = \frac{I_0 V_c^2}{4 V_0 P}, \tag{10}$$

we find the noise power from the beam to be

$$P_b = \frac{I_0}{4V_0C^3}\left|\left(\frac{ju_0C}{\eta}\right)v\frac{\tau}{D} + \left(-\frac{2V_0C^2}{I_0}\right)i\frac{\phi}{D}\right|^2. \tag{11}$$

The thermal noise power is

$$P_t = GkTB = kTB\left|\frac{\xi}{D}\right|^2. \tag{12}$$

Thus the noise figure is

$$F = \frac{P_t + P_b}{P_t} = 1 + \frac{I_0}{4V_0C^3kTB}\left|\left(\frac{ju_0C}{\eta}\right)v\left(\frac{\tau}{\xi}\right) + \left(-\frac{2V_0C^2}{I_0}\right)i\left(\frac{\phi}{\xi}\right)\right|^2. \tag{13}$$

The Gun Region

The gun of a beam-type amplifier consists of a thermionic cathode and various focusing and accelerating electrodes; it produces the electron beam with which the circuit interacts. There are several analyses of electron guns at microwave frequencies. We shall merely state a few general assumptions, and mention the procedure by which the results we use have been derived, referring the reader to the original source for a rigorous derivation. The expression for the noise figure of a backward-wave amplifier derived above contains two unknowns, the alternating velocity and current at the circuit entrance. Watkins,[9] among others, analyzes the potential minimum to anode region of a space-charge limited diode with the Llewellyn-Peterson[10] equations. Strictly speaking, these equations are valid only between parallel plane electrodes of infinite extent. The electrons may move only in a direction perpendicular to the electrodes, by the usual infinite axial magnetic field assumption. The Rack mean-square alternating velocity at the potential minimum is[11]

$$v_a^2 = (4 - \pi)\frac{\eta k T_c B}{I_0}. \tag{14}$$

There is also another source of noise at the potential minimum, namely, the shot noise of the electrons:

$$\overline{i_a^2} = 2eI_0B. \tag{15}$$

Unless noise reduction schemes are incorporated in the gun, this noise is negligible. This shot noise will be neglected until we find the minimum noise figure of a backward-wave amplifier.

Using the values of v and i found by Watkins, we obtain the following noise figures for the specified guns:

Case 1: Space-charge limited emission from cathode to circuit entrance:

$$F = 1 + \frac{(4-\pi)}{2C}\frac{T_c}{T}\left|\frac{\tau}{\xi} - \frac{\phi}{\xi}\frac{\sqrt{2}}{\sqrt{4QC}}\right|^2. \tag{16}$$

Case 2: Space-charge limited emission from cathode to anode, anode followed by drift space followed by circuit; anode, drift space, and circuit at the same potential:

$$F = 1 + \frac{(4-\pi)}{2C}\frac{T_c}{T}\left[1 + 2\left(\frac{\omega_q}{\omega_p}\right)^2\right] \cdot \left|\frac{\tau}{\xi}\cos\beta_q z + \frac{\phi}{\xi}\frac{\sin\beta_q z}{\sqrt{4QC}}\right|^2. \tag{17}$$

Case 3: Same as Case 2 except that the first drift space is followed by a second drift space at the helix potential. The two drift spaces are at different potentials, producing a velocity jump at the velocity maximum:

$$F = 1 + \frac{(4-\pi)}{2C}\frac{T_c}{T}\left[1 + 2\left(\frac{\omega_{q1}}{\omega_{p1}}\right)^2\right]\frac{V_1}{V_2} \cdot \left|\frac{\tau}{\xi}\cos\beta_{q_2} z + \frac{\phi}{\xi}\frac{\sin\beta_{q_2} z}{\sqrt{4QC}}\right|^2. \tag{18}$$

Subscript 1 refers to the first drift space, subscript 2 to the second drift space. By making V_2 large with respect to V_1, the noise figure can be markedly reduced. However, when V_2 becomes larger with respect to V_1, the shot noise, (15), is amplified and may no longer be neglected; in short, the noise figure cannot be reduced without limit by velocity jumps.

The Minimum Noise Figure

A recent publication by Peter and Bloom[8] concerns a theory on the minimum noise figure of a forward-wave traveling-wave tube amplifier. They start at the potential minimum, assuming full shot noise and the Rack fluctuating velocity; they consider the potential minimum to circuit region as an electron beam transmission line of variable impedance. They adjust the expression they find for the noise figure to its minimum value, which is

$$F_{\min} = 1 + 2\sqrt{4-\pi}\,\frac{T_c}{T}\sqrt{4QC}\sqrt{f_{\max}f_{\min}}, \tag{19}$$

where

$$\begin{aligned} f(\psi) &= |\alpha\cos\psi - \beta\sin\psi| \\ 2f_{\max} &= |\alpha|^2 + |\beta|^2 + |\alpha + \beta^2| \\ 2f_{\min} &= |\alpha|^2 + |\beta|^2 - |\alpha^2 + \beta^2|. \end{aligned} \tag{20}$$

It can easily be shown that their parameter α may be

[9] Watkins, *op. cit.*, pp. 11–19.

[10] F. B. Llewellyn and L. C. Peterson, "Vacuum tube networks," PROC. I.R.E., vol. 32, pp. 144–166; March, 1944.

[11] A. J. Rack, "Effect of space charge and transit time on the shot noise in diodes," *Bell Sys. Tech. Jour.*, vol. 17, pp. 592–619; 1938.

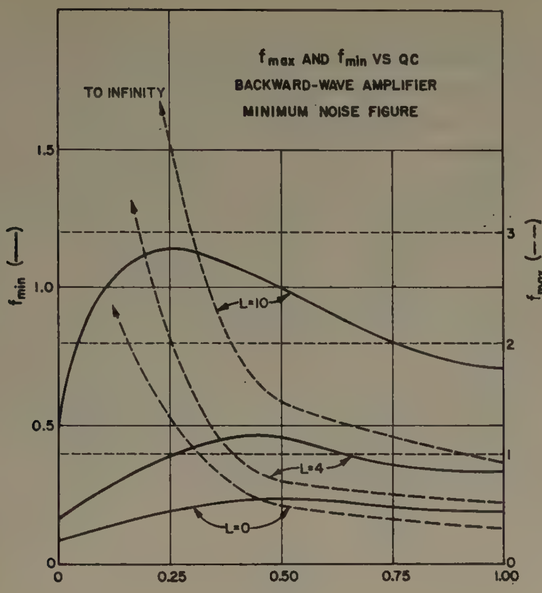


Fig. 2

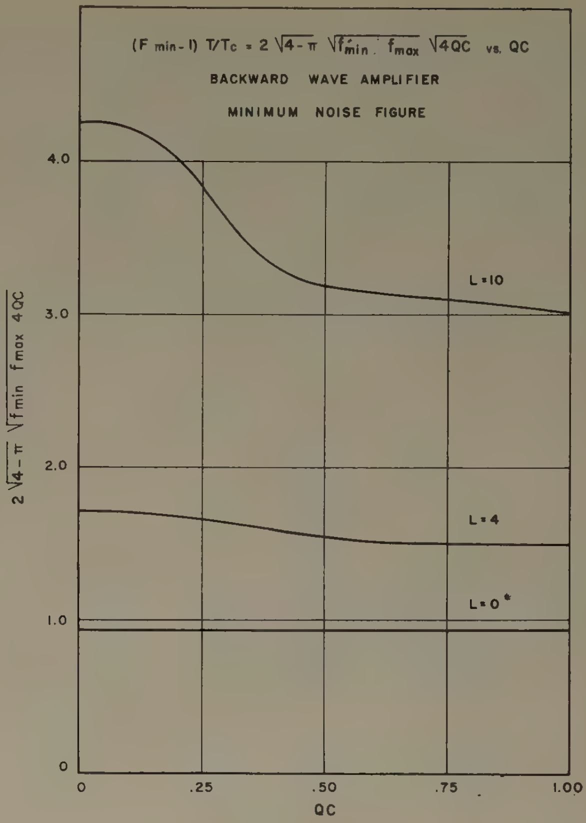


Fig. 3

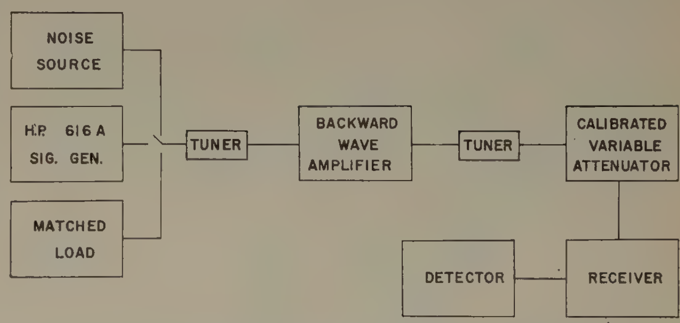


Fig. 4—Block diagram of noise figure measurement.

replaced by our parameter τ/ξ, and their β may be replaced by our $[-\phi/\xi\sqrt{4QC}]$. The $f(\psi)$ of Peter and Bloom is taken directly from Watkins. The expressions derived here are the same as Watkins' if the mentioned replacements are made. We have calculated $f_{\min}$ and $f_{\max}$ for $L=0$, 4, and 10; and for $QC=0$, 0.25, 0.50, 0.75, 1.00.

In Fig. 2, $f_{\min}$ and $f_{\max}$ are plotted versus QC for the three values of loss. In Fig. 3, $(F_{\min}-1)T/T_c$ has been plotted versus QC for the three values of loss. These graphs are the backward-wave analogs of Fig. 2 and Fig. 4 in the above-mentioned paper of Peter and Bloom.[3]

It is interesting to note that the minimum noise figure for the zero loss case ($L=0$) is the same value for both the forward- and backward-wave amplifier, namely,

$$F_{\min} = 1 + .9265\frac{T_c}{T}. \tag{21}$$

Oxide cathodes operate about 1020 K; room temperature may be taken as 290 degrees K. The resulting minimum noise figure is about 6.5 db. Slightly different assumptions about the gun would lower this to about 6.0 db.[12]

In calculating the noise figure for the forward-wave amplifier, it is generally assumed that the circuit is long enough to justify dropping all but the growing wave term. The backward-wave theory described above assumes a CN near the CN of start oscillation, for it is only in this region that appreciable gain is found. Within the framework of these assumptions, it is extremely interesting to note that these two vastly different expressions lead to the same minimum noise figure, if the gun assumptions are the same in both cases. Watkins has shown that a klystron also has a theoretical minimum noise figure of about 6 db. This might indicate that all lossless beam-type amplifiers meeting the same assumptions have the same theoretical minimum noise figure.

If the effects of loss are included in the analysis, the minimum noise figure of a backward-wave amplifier differs from that of the forward-wave amplifier. At $QC=0$, and $L\neq 0$, the backward-wave amplifier has a higher minimum noise figure than the forward-wave amplifier; however, the slope of $(F_{\min}-1)T/T_c$ is negative in the case of the backward-wave amplifier, and positive in the forward-wave amplifier case. Consequently these curves cross, and for QC greater than a

[12] J. R. Pierce and W. E. Danielson, "Minimum noise figure of traveling-wave tubes with uniform helices," *Jour. Appl. Phys.*, vol. 25, pp. 1163–1165; September, 1954.

certain value, the backward-wave amplifier will have a lower noise figure than the forward-wave amplifier. These curves can be used to predict the minimum noise figure of a backward-wave amplifier, if the circuit loss, L, and the space-charge parameter, QC, are known.

Because we wanted to compare our results with the work of Peter and Bloom, we have assumed full shot noise at the potential minimum. It should be mentioned that a recent analysis by Watkins[13] predicts that there is a reduced shot noise at the potential minimum. This reduction lowers the minimum noise figure about 30 per cent for zero loss and space charge, or about 1.5 db.

Experimental Results

The noise figure of a backward-wave amplifier has been measured as a function of gain. Care was taken to match the tube exceedingly well at the frequency of measurement, 3000 mc. The experimental setup is shown in Fig. 4. The experimental procedure was (1) measure the bandwidth of the receiver, (2) calibrate a Hewlett-Packard 616-A signal generator with a standard noise source (which in our case was a fluorescent lamp in waveguide that produced a "white" spectrum 15.8 db above kTB). This calibration gave us a setting, x, on the attenuator of the signal which corresponded to 15.8 db above kTB. Next, the matched load was connected to the tube, the calibrated attenuator was set at 0 db, and the detector reading was noted. Then the H-P 616A was connected to the tube, the calibrated attenuator set at 3 db, and the signal generator's attenuator adjusted to y, where the detector read the same as before. Thus the noise output of the tube, N_{out}, and the signal output, S_{out}, were identical, and both equaled the gain, G, times the signal input S_{in}. Since noise figure is defined

$$F = \frac{N_{\text{out}}}{GkTB} = \frac{S_{\text{in}}}{KTB}, \tag{22}$$

and the signal input is merely the attenuator setting of the signal generator, y,

$$F = y - x + 15.8 \text{ db}. \tag{23}$$

This method of measurement eliminates any errors introduced by the receiver and detector, because the detector reading, and therefore the receiver input, remain constant during each experimental trial. Thus a non-linear, non-square-law detector may be used in this experimental setup.

It should be stressed that the tube used in this experiment was a laboratory model backward-wave oscillator which was operated below starting current, i.e., as an amplifier. No attempt was made to reduce the noise figure. The gun was quite similar to gun pictured in Fig. 1. After three points were measured the tube was accidentally broken. For this reason no checks were made and no measure of experimental error was established. However, because of the method of measurement used, and because of the pains taken to match the tube well, we feel that these points are reasonably accurate. The parameters of this tube for these measurements were $K=3.5$ ohms, $V=990$ volts, $ka=.392$, $\gamma a=6.3$, mean beam radius $b=.202$ inch, mean helix radius $a=.245$ inch, $b/a=.825$, and the start oscillation current, $I_s=1.2$ ma. A longitudinal magnetic field focused the hollow electron beam. Less than 2 per cent of the beam current was intercepted by the helix. The noise figure was calculated assuming space-charge-limited emission from cathode to helix, which is a good assumption for the voltages used. The results of our measurement are shown in Table I, together with the calculated gain of the tube and the calculated noise figures for losses of zero and 4 db.

[13] D. A. Watkins, "Noise at the Potential Minimum in the High-Frequency Diode," *Jour. Appl. Phys.* (to be published).

TABLE I

Loss—db	Beam current—ma	1.1	1.0	0.9
2.4	Gain—db	19.2	13.4	9.6
2.4	F (measured)—db	23.3	23.1	23.8
0	F (calculated)—db	18.0	18.5	18.9
4	F (calculated)—db	22.4	22.7	23.0

Acknowledgment

The author gratefully acknowledges the help of each of the following persons, whose contributions have made this report possible: Dr. H. R. Johnson, who suggested the project and gave valuable aid during its progress; Dr. C. K. Birdsall, who gave advice on the subject of noise; Mrs. Kazi Higa, who performed the necessary computation; and A. M. Anderson and other members of the Engineering Staff, who built the experimental model.

List of Symbols

(in order of appearance)

P_t	Thermal noise power at the tube output, $z=0$.
G	Power gain.
k	Boltzmann constant (1.38×10^{-23} joule/degree Kelvin).
T	Temperature of characteristic impedance matched at the tube input, $z=l$.
l	Tube length.
z	Axial distance measured from circuit entrance.
B	Bandwidth of amplifier.
K	Pierce's impedance parameter, defined for the backward interaction in (1).
E_z	Axial electric field.
β	Circuit propagation constant, ω/v_p, where v_p is cold circuit velocity.
ω	2π (frequency).
P	Total power flow on circuit.
d	Circuit loss parameter of Pierce.

C	Pierce's gain parameter, $(I_0K/4V_0)^{1/3}$.
I_0	Average electron convection current.
V_0	Average beam voltage.
δ	Normalized propagation constant of Pierce.
b	$(u_0-v_p)/Cu_0$, where u_0 is the average electron velocity, $\sqrt{2\eta V_0}$.
QC	Space charge parameter of Pierce.
V_c	Circuit voltage of Pierce (rms).
V	Total voltage of Pierce (rms).
i	Alternating electron convection current, positive if electrons flow toward positive z.
v	Alternating beam velocity, positive toward positive z.
N	l/λ, circuit length in wavelengths.
η	Ratio of electronic charge, e, to electronic mass, m, 1.76×10^{11} coulomb/kg.
L	Total circuit loss, 54.6 CNd decibels.
N	Number of circuit wavelengths.
T_c	Cathode temperature in degrees Kelvin.
e	Electronic charge, coulomb.
j	Symbolizes an imaginary number $\sqrt{-1}$.
ω_q	Reduced plasma frequency, $p\omega_p$ or $p\sqrt{\eta I_0/\epsilon_0 u_0\sigma}$, where σ = beam cross-sectional area, p = plasma reduction factor.
β_q	ω_q/u_0.
$\xi(\delta)$, $\tau(\delta, QC)$, $\phi(\delta, QC)$, $D(\delta, QC)$	parameters defined for convenience after (8).

The Nature of the Uncorrelated Component of Induced Grid Noise*

T. E. TALPEY†, MEMBER, IRE, AND A. B. MACNEE‡, MEMBER, IRE

Summary—**An investigation of induced grid noise in vacuum tubes has been made. It was found that the uncorrelated component of grid noise can be explained in terms of electrons elastically reflected from the plate of the tube. Experimental and theoretical justifications of this explanation are presented. The accuracy of methods for predicting grid noise from measurements of input admittance is affected because of a component of input admittance arising from reflected electrons. A table is included showing typical (measured) values of the induced grid noise of eleven modern receiving tubes.**

Introduction

Two types of vacuum tube noise, shot noise and induced grid noise, are of importance in the design of low-noise, high-frequency amplifiers. Shot noise is the fluctuating component of plate current caused by random variations in the cathode emission rate. Induced grid noise is generated by fluctuations in the number of current pulses induced in the grid circuit by the passage of electrons between grid wires. At the higher operating frequencies, induced grid noise is the limiting factor in low-noise amplifier design.[1,2]

For many years the theory of induced grid noise has been in a rather unsatisfactory state. Calculations based directly on electron transit times yield induced grid noise magnitudes which are consistently low, often by a factor of two or three, (see Fig. 1), while predictions based on measurements of the input admittance are

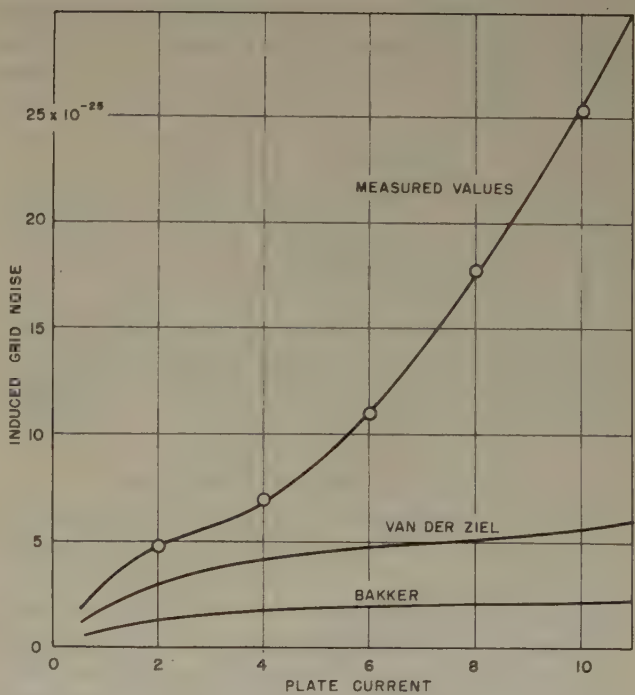


Fig. 1—Comparison between measured and calculated values of mean square induced grid noise current as a function of plate current for one section of a 6J6 double triode at 30 mc. Grid noise is expressed in amperes squared per unit bandwidth, and the plate current in ma.

* Original manuscript received by the IRE, November 30, 1953; revised manuscript received January 4, 1955. This paper is based upon a thesis submitted by T. E. Talpey to the University of Michigan in partial fulfillment of the requirements for the Ph.D. degree in Electrical Engineering. The research was carried out under the guidance of Dr. A. B. Macnee.

† Bell Telephone Labs., Inc. Murray Hill, N.J.
‡ Dep't Elec. Engrg., University of Michigan, Ann Arbor, Mich.

[1] Frequencies above about 15mc for modern miniature tubes.
[2] H. Wallman, A. B. Macnee, and C. P. Gadsden, "A low-noise amplifier," Proc. I.R.E., vol. 36, pp. 700–708; June, 1948.

found to provide a fair amount of agreement with measured grid noise values.[3–5]

It is evident from experimental studies that a large component of the induced grid noise is uncorrelated with the shot noise in the plate current stream.[6,7] Previous writers have suggested two explanations for the origin of this uncorrelated component:

1. Total emission noise[8]—fluctuating currents induced in the grid circuit by electrons returned to the cathode before reaching the potential minimum.
2. Induced partition noise[9]—fluctuations arising because of electron-trajectory variations and inhomogeneities in the electrode structure. It can be thought of as arising from fluctuations in average transit angle.

Consideration of the position of the potential minimum relative to electrode spacings indicates that total emission noise is negligible with respect to the total induced grid noise in tubes such as the 6AK5. Bell[9] has estimated the magnitude of noise to be expected from electron-trajectory variations and concludes that the effect is small under normal operating conditions. The validity of this conclusion has not been completely substantiated by experiment, but it appears that these two explanations alone are not adequate to account for the *observed* excess grid noise.

This paper presents the results of theoretical and experimental studies which indicate that a major portion of the uncorrelated component of induced grid noise is caused by fluctuations in a small number of electrons which are elastically reflected by the plate. These electrons are reflected with sufficient energy to enable them to return through the grid, inducing additional current pulses in the grid circuit. This current increases the input admittance and the induced grid noise. A brief discussion concerning the accuracy of grid noise predictions based on measurements of input conductance or susceptance is included.

For the benefit of the design engineer a table has been included showing typical measured magnitudes of induced grid noise and plate noise for a number of modern miniature receiving tubes.

Analysis of Induced Grid Noise

Theoretical studies, published first by Bakker[3] and recently extended by van der Ziel,[10] show that fluctuations in the cathode emission of a planar triode should produce a mean square induced grid-noise current

$$\overline{i_g^2} = \overline{i_k^2}\left(\frac{\omega\tau_1}{3}\right)^2\left[1 + 2\left(\frac{\tau_2}{\tau_1}\right)\right]^2. \qquad (1)$$

In this equation

$\overline{i_k^2}$ = mean square space-charge-reduced shot-noise component of cathode current, I_k
$= 2eI_k\Gamma^2\Delta f$

τ_1 = transit time from potential minimum to grid-plane

τ_2 = transit time from grid-plane to plate

Γ^2 = space-charge reduction factor

e = charge on an electron $= 1.6\times10^{-19}$ coulomb

Δf = bandwidth in cps.

Eq. (1) is plotted for a typical case in Fig. 1. By a method similar to that described by Goldman[11] it has been shown that to a first approximation the induced grid noise can be expressed as[12]

$$\overline{i_g^2} = \frac{2I_b\Delta f\Gamma^2}{e}\cdot\left|S(\omega)\right|^2, \qquad (2)$$

where

$$S(\omega) = 2\pi G(\omega) = \int_{-\infty}^{+\infty} F(t)e^{-i\omega t}dt. \qquad (3)$$

$G(\omega)$ is the Fourier transform of $F(t)$, the current pulse induced in the grid by the passage of a single electron from cathode to plate [see Fig. 2(a)]. Comparison of (1) and (2) reveals the form of $|S(\omega)|^2$. Since the area of the grid current pulses must be zero, their power spectra and the mean square induced grid-noise current are both proportional to the square of frequency at small transit angles. This observation has been verified experimentally numerous times.[3–6]

The lack of agreement between measured and calculated values of induced grid noise as exemplified by Fig. 1 can be explained in terms of electrons reflected by the plate. It has long been known[13,14] that electrons which are elastically reflected at the plate *of a diode* cause an increase in the shot noise. Strangely enough, no study has been published showing the effect of reflected electrons on grid noise.

An electron which is elastically reflected from the plate has sufficient energy to penetrate the retarding field that it meets between grid and plate. It will very likely succeed in passing back between the grid wires

[3] C. J. Bakker, "Fluctuations and electron inertia," *Physica*, vol. 8, pp. 23–43; January, 1941.
[4] D. O. North and W. R. Ferris, "Fluctuations induced in vacuum tube grids at high frequencies," Proc. I.R.E., vol. 29, pp. 49–50; February, 1941.
[5] R. L. Bell, "Induced grid noise," *Wireless Eng.*, vol. 27, pp. 86–94; March, 1950.
[6] R. Q. Twiss and Y. Beers, "Minimal Noise Circuits," *Vacuum Tube Amplifiers*, vol. 18, Ch. 13, M.I.T. Rad. Lab. Series, McGraw-Hill Book Company, New York N.Y., 1948.
[7] A. van der Ziel, "Noise suppression in triode amplifiers," *Canad. Jour. Tech.*, vol. 29, pp. 540–553; December, 1951.
[8] A. van der Ziel and A. Versnel, "Induced grid noise and total emission noise," *Philips Res. Rep'ts*, vol. 3, pp. 13–23; February, 1948.
[9] R. L. Bell, "Negative grid partition noise," *Wireless Eng.*, vol. 25, pp. 294–297; September, 1948.
[10] A. van der Ziel, "Induced grid noise in triodes," *Wireless Eng.*, vol. 28, pp. 226–227; July, 1951.
[11] S. Goldman, "Frequency Analysis, Modulation and Noise," McGraw-Hill Book Company, New York, N.Y., 356 ff; 1948.
[12] T. E. Talpey, "A Study of Induced Grid Noise," Doctoral Thesis, July 1953, available on microfilm from University Microfilms, Ann Arbor, Michigan.
[13] D. O. North, "Fluctuations in space-charge-limited currents at moderately high frequencies, Part II, diodes and negative grid triodes," *RCA Rev.*, vol. 4, pp. 441–472; April, 1940; vol. 5, pp. 106–124; July, 1940.
[14] G. E. Duvall, "The Effects of Transit Angle on Shot Noise in Vacuum Tubes," M.I.T. Res. Lab. of Electronics, Tech. Rep. No. 82, Sept. 8, 1948.

before it loses its cathode-directed energy and is finally drawn back to the plate again. The pulse of current induced in the grid circuit by such a reflected electron will be approximately three times as long as the pulse produced by an ordinary electron, as indicated in Fig. 2(b).

By the application of two theorems from the study of Fourier integrals[15] it is easily shown that the power spectrum of the complex pulse shown in Fig. 2(b) is given by the following expression:

$$|S_r(\omega)|^2 = |S(\omega) - S(-\omega)e^{j2\omega(\tau_1+\tau_2)} + S(\omega)e^{-j2\omega(\tau_1+\tau_2)}|^2 \quad (4)$$

where $|S(\omega)|^2$ is the power spectrum of the first third of the pulse, up to the point where the electron first arrives at the plate.

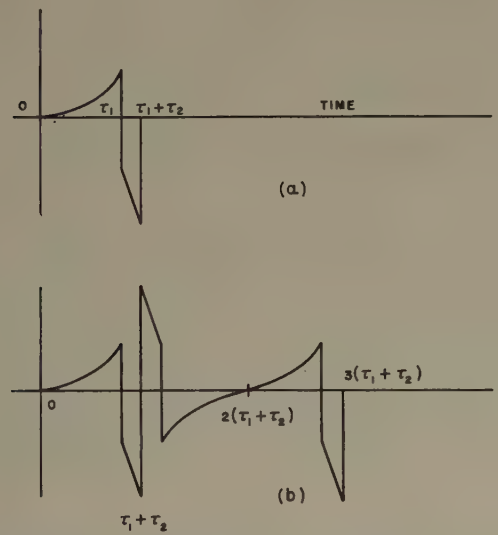


Fig. 2—(a) Current pulse induced in the grid circuit of an ideal space-charge-limited triode by the passage of a single electron, (b) Current pulse induced in the grid circuit by an electron which traverses the tube, is elastically reflected at the plate, succeeds in getting back close to the potential minimum, and then returns to the plate.

Now $S(\omega)$ can be expanded in a power series in terms of $\omega\tau_1$ as follows:

$$S(\omega) = a_1\omega\tau_1 + a_2(\omega\tau)^2 + a_3(\omega\tau_1)^3 + \cdots \quad (5)$$

where the factors a_1, a_2, etc. involve terms in (τ_2/τ_1), $(\tau_2/\tau_1)^2$, etc., as in (1). Assuming that the transit angle $\omega\tau_1$ is considerably smaller than one radian,[16] we can neglect all terms except the first in (5) and write

$$S(\omega) \cong -S(-\omega) \cong a_1\omega\tau_1. \quad (6)$$

Eq. (4) then becomes

$$|S_r(\omega)|^2 \cong |S(\omega)|^2 |1 + 2\cos 2\omega(\tau_1+\tau_2)|^2. \quad (7)$$

If $2\omega(\tau_1+\tau_2)$ is also considerably less than one radian, the cosine is approximately unity and we obtain the relationship

$$|S_r(\omega)|^2 \cong 9|S(\omega)|^2. \quad (8)$$

The reflected electrons thus produce an induced grid noise component given approximately by

$$\overline{i_g^2} = \frac{2\Delta f}{e}(rI_b)(9)|S(\omega)|^2, \quad (9)$$

where r is the reflection coefficient of the plate, that is, the fraction of incident electrons which are elastically reflected.

Since fluctuations in the number of reflected electrons are independent of fluctuations in cathode emission, the induced grid noise components given by (2) and (9) add quadratically, giving as an approximate expression for the total induced grid noise at small transit angles

$$\overline{i_g^2} = \frac{2I_b\Delta f}{e}|S(\omega)|^2[\Gamma^2 + 9r]. \quad (10)$$

Logarithmic extrapolation of experimental data reported by Farnsworth[17] indicate that $r=0.03$ is a reasonable estimate of the reflection coefficient for plate voltages of 100 to 150 volts. Nominal values of Γ^2 lie near 0.1, so that the bracket in (10) becomes

$$[\Gamma^2 + 9r] = [0.1 + .27] = 0.37.$$

The reflected electrons in this case have caused an approximately four-fold increase in induced grid noise. We thus conclude that the reflected electrons are entirely capable of producing the observed excess of measured grid noise over values predicted by earlier theories.

Experimental Verification

The effect of reflected electrons on induced grid noise was verified experimentally by measuring the induced grid noise of a type 6AS6 pentode as a function of suppressor voltage; the results of these measurements are shown in Fig. 3, on the following page.

The induced grid noise increases by a factor of six or so as the suppressor voltage varies from +20 to −20 volts. When the suppressor is negative, it creates a retarding field and some electrons are reflected before they reach the plate. As the suppressor is made more negative, more electrons are reflected until at about −10 volts they are all reflected and the plate current drops to zero. Those electrons which are not captured by the screen travel on toward the grid and induce additional current pulses in the grid circuit.

The correlation between induced grid noise and reflected electrons is even more striking if the data of Fig. 3 are plotted in a different manner. The deficiency in plate current with respect to its asymptotic value at positive suppressor voltages is a measure of the number of electrons which are artificially reflected by the field of the suppressor before they can reach the plate. The grid

[15] See, for example, E. A. Guillemin, "The Mathematics of Circuit Analysis," John Wiley & Sons, New York, N.Y., Ch. VII, Article 22; 1949.

[16] At 30 mc, the transit angles of all the miniature tubes studied are well below 0.1 radian.

[17] H. E. Farnsworth, "Energy distribution of secondary electrons from copper, iron, nickel and silver," *Phys. Rev.*, vol. 31, pp. 405–422; March, 1928

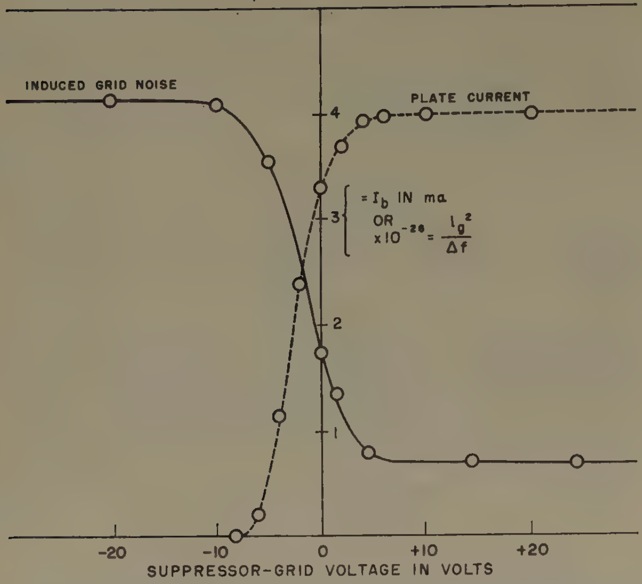


Fig. 3—Mean square induced grid-noise current vs suppressor-grid voltage for a 6AS6 at 30 mc with a fixed control grid voltage and a constant cathode current. The variation in *plate* current is also shown (dashed curve).

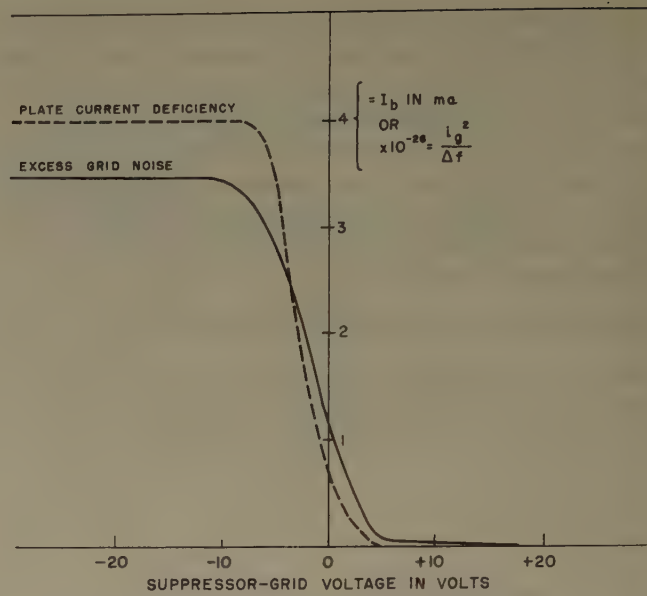


Fig. 4—Excess grid noise and deficiency in plate current (dashed curve) vs suppressor-grid voltage.

noise in excess of its asymptotic value at positive suppressor voltages should be directly proportional to the number of artificially reflected electrons according to (10). When the deficiency of plate current and the excess grid noise are both plotted as a function of suppressor voltage on the same set of coordinates the correlation is excellent, as Fig. 4 clearly shows.

It is significant that the grid noise is appreciably larger for zero suppressor voltage than for positive voltages. When the suppressor is at the same potential as the cathode, the resulting electric field is able to deflect a few electrons sufficiently to prevent them from reaching the plate.[18] These electrons are returned to the vicinity of the control grid and thus cause an increase in the grid noise. If the suppressor connection is brought out to a separate pin, it should be connected to the plate and screen. This eliminates the possibility of reflected electrons being produced by deflection in the screen-suppressor region yet preserves the obstacles presented by the suppressor and screen wires to the return of reflected electrons from the plate. This connection was tried in a 30-mc cascode amplifier[2] employing a 6AS6 input stage. It was found that the noise factor could be reduced from 2.95 to 2.25 db by changing the suppressor connection from the cathode to the plate.

Reflected Electrons and Input Admittance

There is a direct relationship between the electrons which are elastically reflected at the plate of a vacuum tube and the transit-time component of input admittance. This can be demonstrated qualitatively in the following manner. A signal applied to the grid of a tube causes variations in the control-grid voltage which are accompanied by variations in the plate current. For small signals it can be assumed that the reflection coefficient of the plate is constant, so that variations in the plate current will produce proportional variations in the number of reflected electrons.[19] It follows that these reflected electrons must produce, in the grid circuit, a varying induced current which is proportional to the grid voltage. The component of this induced current which is in phase with the grid voltage produces additional input conductance; while the quadrature component produces additional input susceptance. When a measurement is made of the input admittance of a tube, the value obtained includes a component due to reflected electrons as well as the component due to the main electron stream.[20]

Two methods have been advanced for predicting grid noise from measurements of the input admittance. One of these methods[3,4] expresses the grid noise in terms of the transit-time component, G_g, of input conductance:

$$\overline{i_g^2} \cong 4kT\beta G_g \Delta f. \tag{11}$$

The value of the quantity β is usually taken as 5.0, although it is a function of the cathode temperature and certain geometrical factors. Unfortunately, because of lead inductance effects it is frequently more difficult to measure G_g than it is to measure the grid noise directly.

[18] The deflection and subsequent reflection are caused by the combined field of the screen and suppressor grids. The reflection takes place just in front of the suppressor grid. The mechanism is similar to that described by W. G. Dow, "Fundamentals of Engineering Electronics," 2nd Ed., John Wiley & Sons, New York, N. Y., pp. 28–29; 1952.

[19] Sizable variations are being considered here; they should not be confused with the minute random fluctuations which give rise to induced noise. The random fluctuations are superimposed on the variations in plate current.

[20] There is also a component due to feedback from the cathode lead inductance. This feedback usually produces considerable input loading but negligible additional noise.

A second method of predicting grid noise makes use of the following expression:[5]

$$\overline{i_g^2} \cong \overline{i_p^2}\left(\frac{\omega C_e}{g_m}\right)^2, \tag{12}$$

where C_e is the space-charge component of input capacity—*i.e.*, the difference between the input capacity when the tube is operating under normal conditions and the input capacity with the tube biased beyond "cut-off."

Both (11) and (12) imply complete correlation between grid noise and plate noise. Both of these equations were derived under the assumption that both grid noise and plate noise owe their origin to fluctuations in the primary electron stream passing the grid. These fluctuations are affected by space charge in the cathode-grid region and are often said to be "space-charge reduced." On the other hand, fluctuations in the number of reflected electrons are not influenced by space charge in the input region. We are thus led to the conclusion that the grid noise produced by reflected electrons, while linearly related to a component of input admittance, must be related in a slightly different manner than indicated by (11) or (12). The use of these equations for predicting the total induced grid noise consequently involves a certain amount of inaccuracy. Further study of the connection between input admittance and reflected electrons is necessary before the magnitude of the error can be ascertained.

The Induced Grid Noise of Miniature Receiving Tubes

During the course of the research leading to the formulation of the above theory many measurements were made of the induced grid noise of a variety of commercially available receiving tubes. Table I presents a summary of these measurements. Because of its usefulness in network calculations, the induced grid noise values are expressed in terms of an equivalent grid noise conductance (βG_g), based on the representation defined by (11). (No claim for the measurement of G_g alone is intended.) Measurements were also made of the plate noise of these tubes, and the results are presented in Table I in terms of an equivalent shot noise resistance.[13]

The method employed for the measurement of induced grid noise was essentially the same as that described by Bakker.[3] A resonant capacitor was connected from plate to cathode of the tube under test to short-circuit the plate noise and prevent feedback, and the grid was connected directly to the input of a high-gain low-noise amplifier. Noise currents induced in the grid circuit of the tube under test were compared with noise from a temperature-limited diode. The change which occurred in the impedance level of the input circuit when the tube under test was turned on (loading due to transit-time and lead inductance effects) required that a correction be applied to the noise diode reading. The correction was determined from the effect of this loading on the amplifier output level. At 30 mc the effect of lead inductance on *grid noise* is negligible.

The values given in Table I represent the averages of measurements taken on a few tubes of each type, with particular values of voltage and current. Values for any given tube may differ considerably (20 to 30 per cent) from these data, even under the same operating conditions.

The use of a lower grid bias to obtain more plate current was found to cause an increase in grid noise in approximately the same ratio as the g_m was increased. Raising the plate voltage (leaving bias fixed) increases g_m without any appreciable rise in grid noise. It follows that for a given plate-current value, a high plate voltage and high negative grid bias are desirable for the attainment of a low noise figure.

Summary

Experimental and theoretical evidence indicate that the origin of a major portion of the uncorrelated component of induced grid noise is that small fraction of the electron stream which is elastically reflected at the plate of a vacuum tube. It has been shown qualitatively that

TABLE I

Measured Values of Induced Grid Noise at 30mc

Tube type	Number examined	Induced grid noise: Equivalent noise conductance βG_g in micromhos			Plate current I_b in ma	Equivalent shot noise resistance Req.	Transconductance g_m in micromhos
		Average	Lowest	Highest			
6AG5	21	142	112	156	7	480	6,000
6AK5	30	46	36	58	10	460	5,500
6AS6*	4	46	42	52	10	450	5,800
6AU6	17	212	184	254	12	420	6,600
6BC5	6	130	120	142	8	590	5,800
6BH6*	3	224	—	—	10	—	—
6BC6*	10	174	144	194	12	410	7,300
6J4	2	200	—	—	15	321	12,000
6J6†	10	60	42	82	8	720	4,400
2C51†	8	40	38	46	8	550	5,400
404A	9	72	68	36	15	240	16,000

* Suppressor connected to plate and screen.
† Values are for a single section.

the presence of reflected electrons will affect the accuracy of induced grid noise predictions based on measured values of input admittance.

It is conceivable that the effect of reflected electrons could be eliminated or materially reduced by the use of a specially constructed tube. If this could be done, the remaining induced grid noise would be more completely correlated with shot noise. By properly detuning the input circuit of a suitable amplifier, it should then be possible to use this correlation to cause a partial cancellation of the effects of induced grid noise and thereby obtain substantially lower noise figures at high frequencies.

ACKNOWLEDGMENT

The authors would like to thank Professors W. G. Dow and G. Hok of the University of Michigan for helpful discussions during the course of this study.

On the Possibility of Amplification in Space-Charge-Potential-Depressed Electron Streams*

WALTER R. BEAM†, MEMBER, IRE

Summary—**Hahn-Ramo theory is used to derive a characteristic wave equation for an electron stream whose single-valued velocity is a function of spatial co-ordinates. A means of solving this equation is found, for the particular case of two-dimensional Cartesian coordinates. A specific, but practical, linear velocity distribution is assumed. It is shown that for several types of boundary conditions, the only waves which can be set up in such a beam are purely propagational and not growing, bearing out the result derived by an approximate method by G. Kent.**

Numerical analysis for a cylindrical beam with potential depression was performed by a digital computer. As before, the results showed absence of any growing waves.

In order to check early results of Haeff,[1] which appeared to show the possibility of gain in single beam devices, an experiment was set up whereby a movable pickup cavity measured the amplitude of space-charge waves at a number of points along a drift tube.

Outputs were compared at different drift lengths for pulsed and continuous operation. No evidence of growing waves was observed, verifying the analytical results. It was found, however, that operation of the collector electrode at very low potentials created secondary electrons which returned to the gun region, were reflected, and then they flowed back with the primary beam. This double-stream action produced electronic gains up to 30 db. It is believed that either a similar effect, or else a space-charge wave gain produced as a direct result of nonuniform beam flow, can explain any signal gains found in conventional single-stream tubes.

INTRODUCTION

SEVERAL years ago, the double-stream amplifier, a mechanism for obtaining amplification in electron streams, was described by several authors.[1–4] It has been shown analytically and experimentally that the mixture of two homogeneous electron streams of slightly different velocity should give rise to exponentially increasing space-charge waves, the result of the perturbation of the two original sets of space-charge waves by one another. Other authors[5–8] have expanded this theory to general multiple-stream amplifiers, with finite boundaries. These theories indicate an optimum gain when only two distinct velocities are present. For the case of homogeneous mixtures of beams of different velocity, it has been shown that velocities in a Gaussian distribution cannot give rise to amplification.[8] A general proof given by Walker[9] indicates that a homogeneous mixture of electrons whose velocity distribution is flat or monotonic, or has a single maximum, cannot produce gain.

Some of the experimental data presented in Haeff's paper[1] indicated large amplification in the case of an electron stream coming from a single cathode. It was proposed that the observed gain was a consequence of the spatial velocity distribution caused by space-charge depression of potential. This had not been taken into account in the existing analyses, which dealt with a one-dimensional problem. A considerably more complicated problem results when the electron velocity is made a spatial function. Kent[10] has used a series approximation to show that gain cannot be self-consistent in a ribbon beam having space-charge depression of potential. The

* Original manuscript received by the IRE, September 24, 1954; revised manuscript received, January 7, 1955. Adapted from a dissertation submitted in partial fulfillment of the requirements for the Doctor of Philosophy Degree at the Univ. of Maryland, College Park, Md.

† RCA Laboratories, Princeton, N.J.

[1] A. V. Haeff, "The electron-wave tube," PROC. I.R.E., vol. 37, pp. 4–10; January, 1949.

[2] L. S. Nergaard, "Analysis of a simple model of a two-beam growing wave tube," *RCA Rev.*, vol. 9, pp. 585–601; December, 1948.

[3] J. R. Pierce and W. B. Hebenstreit, "A new type of high frequency amplifier," *Bell Sys. Tech. Jour.*, vol. 28, pp. 33–51; January, 1949.

[4] A. V. Hollenberg, "Experimental observation of amplification by interaction between two electron streams," *Bell Sys. Tech. Jour.*, vol. 28, pp. 52–58; January, 1949.

[5] P. Parzen, "Theory of space-charge waves in cylindrical waveguides with many beams," *Elect. Commun.*, vol. 28, pp. 217–219; September, 1951.

[6] J. R. Pierce, "Double-stream amplifier," PROC. I.R.E., vol. 37, pp. 980–985; September, 1949.

[7] C. K. Birdsall, "Interaction Between Two Electron Streams for Microwave Amplifications," Tech. Rep. No. 36, Elec. Res. Lab., Stanford Univ., Palo Alto, Calif.

[8] H. Haus, "A Multivelocity Electron Stream in a Cylindrical Drift Tube," unpublished report, Res. Lab. Elec., MIT; June 5, 1952.

[9] L. R. Walker, "The dispersion formula for plasma waves," *Jour. Appl. Phys.*, vol. 25, p. 131; January, 1954.

[10] G. Kent, "Space charge waves in inhomogeneous electron beams," *Jour. Appl. Phys.*, vol. 25, pp. 32–41; January, 1954.

present paper contains a solution of the same problem, in a more rigorous manner. In addition, the space-charge wave modes for the more practical case of a cylindrical beam have been calculated numerically. The results in both cases strengthen the general conclusions reached earlier in the one-dimensional cases.

Formulation of the Problem

The basic method used in problems involving space-charge interaction is the Hahn-Ramo method.[11–12] This assumes: (1) a linear interaction in which the perturbations of space-charge density and electron velocity are small fractions of their average values, (2) that all-time varying quantities are of the form $f_T e^{j\omega t - \gamma z}$, where: f_T indicates a function of the transverse co-ordinates only, ω is the angular frequency of the perturbation, γ is the propagation constant (in general complex), z is the direction of electron velocity, t is time; and (3) electron velocities are single-valued functions of position.

The particular situation to be discussed involves an electron beam of space-charge density ρ and velocity v (the average values of which, ρ_0 and v_0, are functions only of the co-ordinates transverse to z), moving in free space or bounded at or beyond its edge by perfectly conducting metal walls. An infinitely strong axial magnetic field assures zero transverse velocity.[13]

To obtain a solution for the waves in an electron beam one employs Maxwell's equations:

$$\begin{aligned} \nabla \times \bar{H} &= \rho\bar{v} + \epsilon_0 \frac{\partial \bar{E}}{\partial t} \\ \nabla \times \bar{E} &= -\mu_0 \frac{\partial \bar{H}}{\partial t} \\ \nabla \cdot \bar{E} &= \rho/\epsilon_0 \\ \nabla \cdot \bar{H} &= 0 \end{aligned} \tag{1}$$

and the equation of motion of an electron

$$m\left[\frac{\partial \bar{v}}{\partial t} + v_x \frac{\partial \bar{v}}{\partial x} + v_y \frac{\partial \bar{v}}{\partial y} + v_z \frac{\partial \bar{v}}{\partial z}\right] = e[\bar{E} + \bar{v} \times \bar{B}]. \tag{2}$$

The velocity and space charge are separated into static part and perturbation. All cross-products of perturbations are neglected. The equation involving the axial component of electric field can be simplified to the following form:

$$\Delta_t^2 E_z + \left[\gamma^2 + \frac{\omega^2}{c^2}\right]\left[1 + \frac{\rho_0\eta/\epsilon_0}{[j\omega - \gamma v_0]^2}\right] E_z = 0. \tag{3}$$

Δ_t^2 is the Laplacian operator of the transverse axes, c the velocity of light, η the charge-mass ratio of the electron, and ϵ_0 the permittivity of free space.

Eq. (3), if solved under particular boundary conditions, is a characteristic equation specifying characteristic values of γ. Values of γ in the second quadrant of the complex plane are necessary for gain.

The solutions of (3) are real for purely imaginary γ, and complex for complex γ. In cases where there is no gain, the values of γ correspond to solutions having none, one, two, three, etc., zeros interior to the range of solution. The solutions having no zeros (except, perhaps, at the boundaries) are the familiar space-charge waves of the low-level klystron.

Velocity and Space-Charge Distribution

The space-charge density distribution chosen will greatly influence the values of γ. For practical reasons, we shall choose ρ_0 to be constant over the beam, and zero outside the beam proper. This distribution is not too far from that which can be obtained experimentally.

The velocity distribution will be chosen to approximate that found in an electron beam whose potential is depressed by space-charge forces. For an axially cylindrical, drifting beam, the solution of Poisson's equation

$$\nabla^2 V = -\rho_0/\epsilon_0$$

gives:

$$v_0 \sim v_{00} + \frac{\rho_0\eta}{4\epsilon_0 v_{00}} r^2, \tag{4}$$

where v_{00} is the value of v_0 on the axis and r is distance from the axis.

For a two-dimensional "ribbon" beam of infinite extent in the y direction, the solution of Poisson's equation will depend on the potential of the electrodes bounding the beam in the x-direction. One possible solution is linear in x. This is particularly interesting, for it is the only distribution leading to a transformation enabling analytical solution.

Boundary Conditions

In any experimental space-charge amplifier the beam must be enclosed in metal walls. This is essential in order to prevent excessive potential depression due to space charge and to eliminate the effects of charge on insulating walls. Space-charge wave solutions for multiple-stream amplifiers show that the presence of metal walls very near the beam tends to inhibit the interaction of electrons near the wall. Furthermore, if the wall is removed by a distance greater than the order of the distance between bunches, its effect becomes negligible. There is no evidence that intermediate positions of the enclosing walls can produce any new effects.

The boundary conditions of (3) at metal walls are $E_z = 0$. At the center of an axially symmetrical system not containing a line charge on the axis, $\partial E_z/\partial r = 0$.

When the electron beam does not completely fill the space enclosed by the metal walls, an additional bound-

[11] W. C. Hahn, "Small signal theory of velocity-modulated electron beams," *Gen. Elec. Rev.*, vol. 42, pp. 258–270; June, 1939.

[12] S. Ramo, "The electronic-wave theory of velocity modulation tubes," Proc. I.R.E., vol. 27, pp. 757–763; December, 1939.

[13] Of course, relaxing the restraint on transverse velocities allows other types of interaction, some of which can give rise to gain. This is beyond the scope of this paper.

ary condition must be satisfied at the boundary between the electron beam and free space. Outside of the beam $\rho_0=0$, making the solution much simpler in that region. It may be expressed as the sum of two linearly independent solutions, whose coefficients are determined by requiring that E_z and its transverse gradient be equal on each side of the boundary.

Cartesian Case

Ribbon Beam: If the electron beam in question is infinite in extent in the y direction, and has the linear velocity distribution described above, (3) will become

$$\frac{d^2E_z}{dx^2}+\left(\gamma^2+\frac{\omega^2}{c^2}\right)\cdot\left[1+\frac{\rho_0\eta/\epsilon_0}{\left[j\omega-\gamma\left(v_{00}+\frac{dv_0}{dx}x\right)\right]^2}\right]E_z=0. \tag{5}$$

This assumes no y-components of field or velocity. The further assumption will be made that the wave velocity of a desired solution is much less than the velocity of light c. In that case:

$$\frac{\omega^2}{c^2}\ll|\gamma^2|,$$

and the ω^2/c^2 term may be dropped from the equation. A transformation, used first by MacFarlane and Hay[14] in the solution of the crossed-field amplifier, may be applied. Let:

$$u=\frac{\omega+j\gamma v_0}{\dfrac{dv_0}{dx}}; \tag{6}$$

then (5) may be reduced to:

$$\frac{d^2E_z}{du^2}-\left[1-\frac{\omega_0^2}{\left(\dfrac{dv_0}{dx}\right)^2u^2}\right]E_z=0. \tag{7}$$

The ω^2/c^2 term has been dropped, and the notation $\omega_0=\sqrt{\rho_0\eta/\epsilon_0}$ used. ω_0 is commonly denoted the "plasma frequency."

It is a characteristic of the linear velocity distribution that $dv_0/dx=\omega_0$. Eq. (7) then reduces to the simple form:

$$\frac{d^2E_z}{du^2}-\left(1-\frac{1}{u^2}\right)E_z=0 \tag{8}$$

free of explicit dependence on γ. The method of solution will be to first determine a solution satisfying the desired boundary conditions in the u variable, and then transform from u back to x, obtaining γ in the process.

The boundary conditions at a metal wall are $E_z=0$. For a beam not enclosed by conducting walls at its edges, the solution outside the beam must satisfy

$$\frac{d^2E_z}{dx^2}+\gamma^2E_z=0.$$

Such solutions are $e^{\pm j\gamma x}$.

The solution for a beam in free space must vanish at infinity. Hence only the $e^{j\gamma x}$ term is allowable for large positive x, and $e^{-j\gamma x}$ for negative x. For positive x the matching condition

$$\frac{1}{E_z}\frac{dE_z}{dx}=+j\gamma$$

is replaced by

$$\frac{1}{E_z}\frac{dE_z}{du}=-1$$

in the u plane. On the negative x side of the beam,

$$\frac{1}{E_z}\frac{dE_z}{du}=+1$$

is the matching condition.

Since γ is not known, the mapping of x into the complex u plane is not known. Because (8) does not contain γ, it can be solved, two independent solutions being found. These solutions, combined linearly, encompass an entire class of physical problems, and by proper combination of the two solutions, each allowed γ for a particular set of parameters can be located.

Two values of u(u_A and u_B) must be found for which the boundary conditions at the beam edges (x_A and x_B) are satisfied; and for some complex γ and for given $v(x_A)$ and $v(x_B)<v(x_A)$, they must transform into real values of x. For given $v(x_A)$ and $v(x_B)$ there is a countable set of such u_A and u_B. The requirements on u_A and u_B are shown in Fig. 1 (opposite). Since u is linear in x and, more directly, in $v_0(x)$, the line joining u_A and u_B must pass through $u=\omega/\omega_0$, which for practical tubes is of the order of 10 or more. u_A and u_B must also be the proper distances from $u=\omega/\omega_0$ so that the ratio of these distances equals the ratio of v_A to v_B. A requirement for gain modes is that u_A to u_B fall in the first and second quadrants of the u plane, or, alternatively, in the fourth and third quadrants, so that the phase velocity of the wave will lie somewhere between v_A and v_B. This is a general requirement on growing waves produced by systems of different velocities.[15]

Under the boundary conditions required by conducting walls at x_A and x_B, we require the solution $E_z(u)$ to have zeros at u_A and u_B. If u_A and u_B satisfy the other stated conditions, $E_z(u)$ along the line joining u_A and u_B gives the solution along the corresponding segment of the x-axis. We now proceed to show that no such u_A and u_B giving rise to gain do exist.

[14] G. G. Macfarlane and H. G. Hay, "Wave propagation in a slipping stream of electronics: small amplitude theory," *Proc. Phys. Soc.*, B. 63, pp. 409–426; June 1, 1950.

[15] C.f., J. R. Pierce, "Coupling of mode of propagaton," *Jour. Appl. Phys.*, vol. 25, pp. 179–183; February, 1954.

In order to find such u_A and u_B, $E_z(u)$ must be determined over a large part of the complex u plane. Let a particular pair of independent solutions of (8) be called $f_1(u)$ and $f_2(u)$. The general solution is $c[f_1(u)-\phi f_2(u)]$, in which c and ϕ are arbitrary complex numbers. We are only interested in the zeros of solutions, since u_A and u_B must be among them. All zeros of all linear combinations can be found by plotting f_1/f_2. Choosing a point where $\phi=\phi_0$, we search for other points where $f_1/f_2=\phi_0$. These points are all zeros of some particular solution of (8). Curves may be drawn (in the u plane) along which f_1/f_2 varies recurrently through the same set of values. These we call the loci of zeros of the solutions, and on them the next argument will be based.

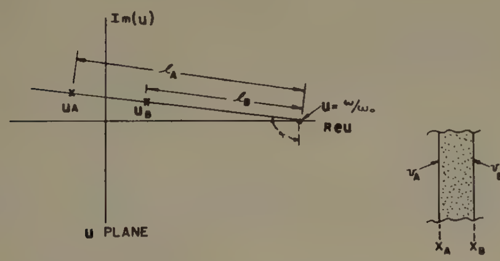


Fig. 1—Illustrating the relation two points u_A and u_B must satisfy to define a solution to (4) with zero boundary conditions. the relation $l_A|l_B=v_A|v_B$ must hold, and a line through u_A and u_B must intersect the real u axis at $u=\omega/\omega_2$. Then $|y|=|l_A|/v_A=|l_B|/v_B$; $\arg\gamma=\alpha$.

Consider the equation

$$\frac{d^2E_z}{du^2}+\frac{1}{u^2}E_z=0. \tag{9}$$

For u sufficiently less than unity in absolute value, (8) approaches (9). Similarly, solutions of (8) become asymptotic to those of (9) in the same region.

Two solutions of (9) are

$$\sqrt{u}\sin\left(\frac{\sqrt{3}}{2}\ln u\right) \quad\text{and}\quad \sqrt{u}\cos\left(\frac{\sqrt{3}}{2}\ln u\right).$$

The zeros of these functions lie on the positive real u axis, and loci of zeros of arbitrary solutions of (9) in the u plane are radial lines.

If ju is substituted for u in (8), one obtains:

$$\frac{d^2E_z}{d(ju)^2}+\left(1+\frac{1}{(ju)^2}\right)E_z=0. \tag{10}$$

For real ju, that is, imaginary u, the solutions of (10) will be oscillatory, with zeros lying on the imaginary u axis. The origin is a branch point and essential singularity, as in the asymptotic functions. The loci of zeros of arbitrary solutions of (10), which also qualify as zeros of solutions of (8), will lie as illustrated in Fig. 2. Since $f(-u)$, $f(u^*)$ and $f(u)$ all satisfy (8), all loci have counterparts in each quadrant.

The search for points which satisfy all requirements on u_A and u_B for gain is fruitless, for none of the loci illustrated in Fig. 2 could pass through two such points as are shown in Fig. 1. We conclude that no gain modes are possible.

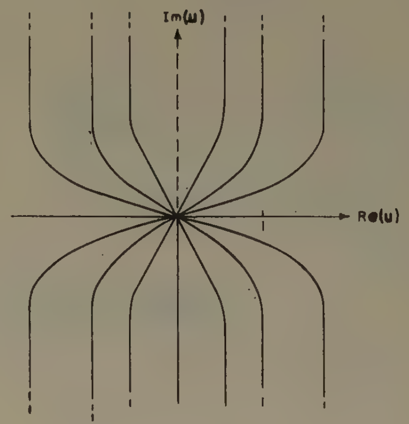


Fig. 2—Shapes of the loci of zeros of solutions to (4). Each radial line represents the locus of zeros of a set of independent solutions.

For the propagating modes which do exist, u_A and u_B lie on the real u axis, and must be spaced appropriately with respect to the ω/ω_0 point. Within the limitations of u_A and u_B can be found one infinite set of zeros lying on the positive real u axis, and one on the negative real u axis. These give rise to two sets of characteristic values of γ, one of which gives waves with phase velocity $>v_A$ and the other with phase velocity $<v_B$. No waves are found which have the velocity of any of the electrons. In the two lowest order modes E_z has no zeros between x_A to x_B. The next two modes, with velocities closer to electron velocities, have a zero of E_z between x_A and x_B. Such modes would be hard to detect, for most detectors (cavities, helixes) indicate an integrated value of the field over the beam. The other modes are of successively higher order, and their only importance in practice is the power which they make unavailable for output. The modes of this "ribbon" beam have velocities similar to those calculated for a cylindrical beam in Fig. 3, on the following page.

It is interesting to postulate $(dv_0/dx)\neq\omega_0$, to determine whether a large artificially produced linear velocity distribution could give amplification. For smaller velocity gradients

$$\left(\frac{dv_0}{dx}<\omega_0\right),$$

the form of the solutions will be similar to those discussed above, except that the characteristic values of the propagation constant will be closer to one another.

If the gradient $(dv_0/dx) \geqq 2\omega_0$, the solutions show only two possible values of γ, whose velocities correspond to the beam velocity at the two edges. For such high velocity gradients, the assumption of a plane wave solution is somewhat questionable. Particularly simple solutions are derived when $v_0' = 2\omega_0$, these being reducible to Bessel functions of zero order. Such solutions were examined in detail and found to produce no gain modes.

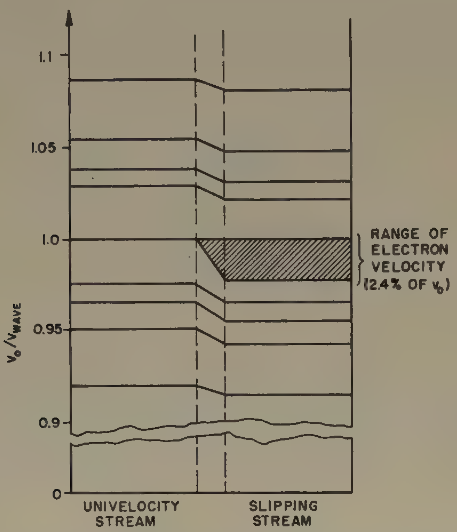


Fig. 3—Computed propagation constants of eight lowest modes of an electron beam with and without slip.

To obtain values of γ for a beam in free space, consider an arbitrary solution of (8), characterized by its locus of zeros. Its derivative dE_z/du also has zeros along approximately the same line (required by the approximate symmetry of the function near its locus of zeros). The function $(dE_z/du)/E_z$ has alternating zeros and poles along and near the locus.

Since E_z is real along its locus of zeros, the points at which the function $(dE_z/du)/E_z$ has values of ± 1 lies along a line which is very near a locus of zeros.

The same argument as before may be used to show the absence of gain modes.

The solution for the case of a beam enclosed by conducting walls at a distance is not readily visualized, and will not be discussed. It may be expected to yield the same results.

The case of an electron beam in which the (linear) velocity distribution has even symmetry about the center may be easily investigated, for the symmetry of velocity requires even or odd symmetry in the solution. For odd symmetry, the solution must be zero in the beam center, a simple boundary condition. For solutions with even symmetry, the first derivative must be zero at the center. Since the locus of zeros of dE_z/dx lies almost upon that of E_z, no new results would be expected.

Thus we have found that in the case of a "ribbon" beam, the only difference between a "slipping" beam and a beam with uniform velocity is the altering of propagation constants of the space-charge waves. This effect is small, and no attempt was made to measure it in the experiments. It is perhaps harmful in the operation of very high current traveling-wave tubes, where bandwidth is already limited by high space-charge density, for the effect is similar to that of a higher space-charge density.

Cylindrical Beam—Computed Solutions: The more practical problem of a cylindrical, axially symmetrical beam with velocity distribution described by (4) was also attacked. All attempts at analytical solution having met with no success, the problem was presented to the Institute for Advanced Study Electronic Digital Computer.

The method chosen for preliminary analysis was to solve the appropriate form of (3),

$$\frac{d^2E_z}{dr^2} + \frac{1}{r}\frac{dE_z}{dr} + \left(\gamma^2 + \frac{\omega^2}{c^2}\right) \cdot \left(1 + \frac{\omega_0^2}{[j\omega - \gamma v_0]^2}\right) E_z = 0 \qquad (11)$$

for chosen values of γ and attempt to determine values of γ satisfying the boundary conditions. A complete mesh survey of the γ plane required excessive time, while iteration and successive approximations might not converge correctly when handled by the computer. The chosen method consisted of forward integration of (11) satisfying the boundary conditions $E_z' = 0$ at $r = 0$, to the final value of r, at the conducting boundary. The value $E(\gamma, r_{\text{boundary}})$ was called $f(\gamma)$. It is zero only for γ satisfying the boundary conditions, and since the coefficients of (11) are regular except at $\gamma = j\omega/v_0$, the function of $f(\gamma)$ will be analytic everywhere in the finite plane except on portions of the imaginary axis.[16] We are thereby led to the method of counting zeros of a complex function inside a closed contour by measuring the increase in arg $f(\gamma)$ as γ traverses a chosen contour (Nyquist's criterion).

The net number of times $f(\gamma)$ encircles the origin, in the absence of singularities of the function within the contour, equals the number of zeros in the contour of γ. For the present problem, contours of γ are chosen such that all gain modes of interest would lie inside. These contours do not contain the imaginary axis of γ, where the singularities of the equation are known to lie. γ is traversed point-by-point, with a sufficiently fine mesh so that $f(\gamma)$ does not proceed more than 90 degrees between two successive points. A record is made when $f(\gamma)$ crosses the co-ordinate axes, with due regard to direction. When the contour is closed, four quantities are obtained, being the net number of times each of the four major axes was crossed in a specified direction. These should all be equal to the number of zeros in the contour. This provides a useful check of the method.

[16] This quality of the solution results from a theorem of Fuchs; see, for example, E. T. Copson, "Introduction to the Theory of Functions of a Complex Variable," Oxford Univ. Press, Oxford, Eng., pp. 233–34; 1935.

In the light of the negative analytical and experimental results, the root-counting code was used only in broad sweeps of the γ plane; for practical constants it was confirmed that no roots were present. By confining the operation to purely imaginary values of γ, the propagational modes were computed. In Fig. 3 are shown some mode velocities calculated for a slipping cylindrical stream, as compared with mode velocities of an equivalent univelocity beam. The beam used in this calculation was 0.080 inch in diameter and completely filled its drift tube. Beam-center voltage was 100 volts and current 6 milliamperes.

Experimental Investigation

Although the analytical and computed results did not make the chance of finding gain experimentally seem optimistic, it was still felt that some gain phenomenon might arise from the complicated electron flow conditions arising in a practical tube. A demountable tube was constructed, the main features of which are illustrated in Figs. 4 and 5. The tube consists of an evacuated glass envelope, inside of which is a cylindrical brass frame. This frame acts as an aligning jig for the electron gun, the two resonant cavities, the collector, and a beam diameter measuring iris. The electron gun used throughout the investigation has an 0.050-inch diameter oxide cathode and produces a beam which can be readily confined to 0.060-inch diameter through the length of

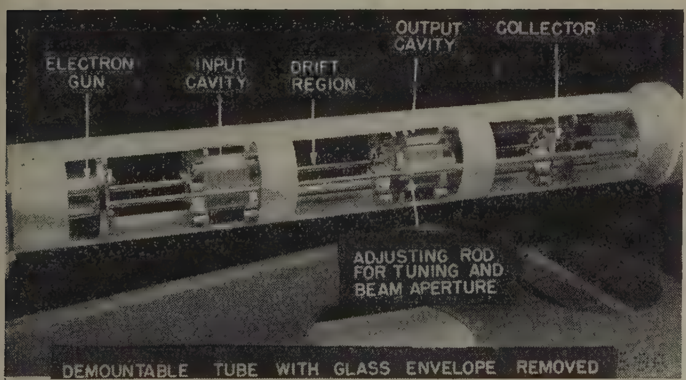


Fig. 4—Experimental demountable tube.

the tube, about fifteen inches from gun to collector. In most of the experiments, the electron beam was surrounded by a set of four molybdenum tapes, which formed a drift space of square cross section, 0.125-inch on a side. The tapes are 0.001-inch thick, and can be made to roll on rollers around the cavities. In this way cavity movement is possible without varying the drift region cross section.

Among the refinements in this demountable tube assembly are: cavities which can be tuned and matched from outside the vacuum, interchangeable collector assembly, and a diaphragm with apertures of graded diameter for measuring beam size by interception of current on the diaphragm. Tuning and adjustment of the beam aperture is performed by means of a rod having a half-gear attached, which meshes with other gears in the tube to perform these functions. The liquid-air cooled vacuum system can maintain a pressure of 5×10^{-8} mm Hg.

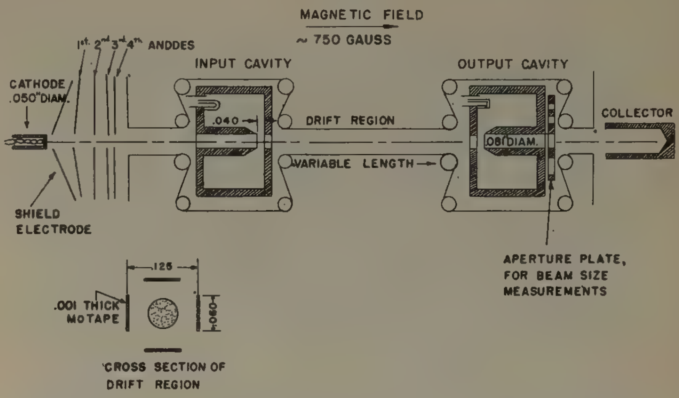


Fig. 5—Diagram of experimental demountable tube (not to scale).

The radio frequency system is sketched in Fig. 6. The loop in each resonant cavity is fed from the coaxial line through a nonmatched hermetic seal. The coaxial line is rigid, and emerges through an O-ring gland seal. Cavities are moved longitudinally by pushing and pulling on this coaxial line; coupling is adjusted by rotating the line, thereby rotating the loop inside the cavity. This has proved to be a satisfactory type of coupling for this type of work, in which little signal power is involved, and fairly large losses are tolerable.

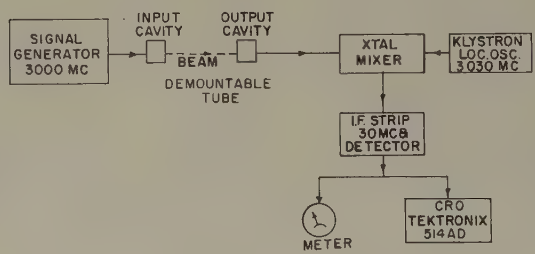


Fig. 6—Block diagram of radio frequency system.

The initial experiments were designed to determine if increasing waves could be set up in a slipping cylindrical stream of electrons. In order to insure that positive ion neutralization of the beam would not destroy the velocity difference, experiments with a continuous beam were compared with experiments in which the beam current was pulsed by application of one microsecond pulses to a gun electrode. In both these cases the measurement consisted of applying signal to the input cavity and observing the output voltage while the voltage of the entire cavity system and drift region was swept with

respect to that of the gun electrodes. Typical of the observed waveforms are those shown in Fig. 7. The curves on the right differ from those on the left only in that they contain the pulse edges; it is the envelope of the curve which is of consequence. Fig. 7 illustrates that there is no difference in the space-charge waves under pulsed or continuous operation.

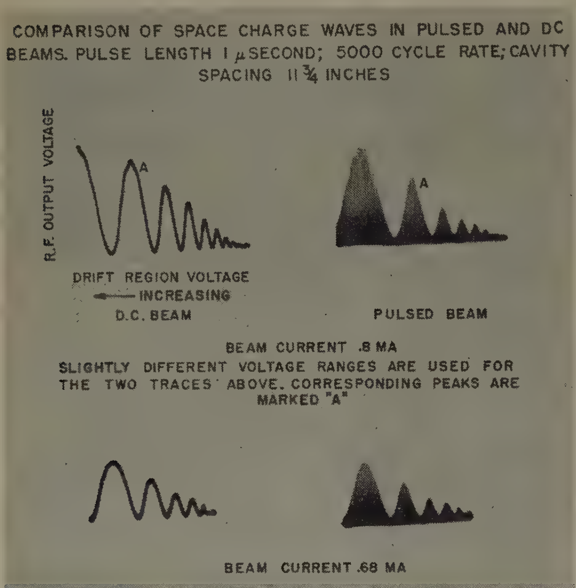


Fig. 7—Output voltage vs drift potential, for pulsed and for continuous beam. Pulse length, one microsceond; cavity spacing $11\frac{3}{4}$ inches; beam current 0.8 ma. Corresponding peaks marked "A."

The curves obtained by sweeping cavity and drift-tube voltage, for a tube with infinitesimally short cavity gaps, are expected to be of the form $|\sin 2\pi z/\lambda_p|$, where z is the cavity spacing and λ_p the plasma wavelength of the space-charge waves. λ_p is a monotonically decreasing function of drift voltage. The curves shown have a decided decrease of amplitude at low voltages. This may be explained by the effect of transit time in the cavity gap. The curves of Fig. 7 are typical of results obtained with a two-cavity tube having no exponential gain; it is simply a low-level klystron.

To make a sensitive determination of the presence or absence of exponential gain, it is only necessary to make several such records with different cavity spacings. Any exponential gain will show up as a higher output at larger cavity spacing. Naturally, the number of maxima will increase as the spacing is increased, for each maximum is a measure of one plasma half-wavelength. If gain occurs as a result of space-charge depression of potential, the effect should be greater at low-drift voltages. This should show up as an increase in the height of the curve at the low-voltage end. In Fig. 8, showing curves taken at three-cavity spacings, the curve envelopes are all the same, indicating absence of exponential gain. The tube was operated over a wide range of beam currents, up to four milliamperes, with similar results.

From the known beam diameter and velocity the theoretical velocity variation from beam center to edge was determined. The amount of gain produced by the equivalent double-stream amplifier with half its electrons having the velocity of the beam center and the other half at the edge velocity would be, for a tube of the length used here, about 30 db, under typical voltage and current conditions. Gain in the electron beams observed, due to slipping, was definitely nonexistent.

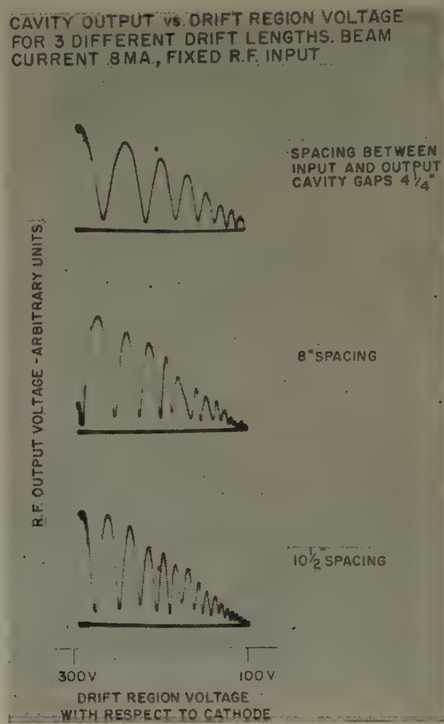


Fig. 8—Output voltage vs drift potential as a function of drift length. Beam current 0.8 am. Rf input fixed.

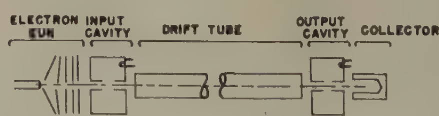


Fig. 9—Diagram of tube of the type used by Haeff.

In a second set of experiments, the drift region of the tube was altered so that it was somewhat similar to that described by Haeff[1] (see Fig. 9). The tape assembly was replaced by a metal cylinder of greater diameter which could be operated at a potential different from the cavity potential. Again, the potential of the drift region

was swept. Results were very similar to those of Figs. 7 and 8, except that the transit-time effect of the gaps could be eliminated by operating the cavities at a high, fixed potential.

It was found that with this configuration, curves such as shown in Fig. 10(b) could be obtained at very low-collector potential (50 to 150 volts). This may be interpreted as exponential gain, since the curve rises at low voltage, superimposing the gain on the usual oscillatory space-charge wave solution. The mechanism operating here could not have been observed by Haeff[1] because it requires a lower collector voltage than he employed. The gain observed at low-collector voltage was finally traced to secondary electrons emitted at low velocity from the collector, focused back through the cavities and drift tube, reflected from the region in front of the cathode, and refocused through the tube. These secondary electrons, having energy approximately equal to that of the primary beam less the collector potential, could not return to the cathode. With carefully adjusted gun voltages and collector voltage, the primary and secondary beams interacted as a double stream to produce an output above 30 db higher than the normal space-charge waves. The net gain of the device was never positive, but since the space-charge wave gain (klystron gain) of a tube can be greater than unity, the mechanism could produce net gain if used in a tube with better beam-to-cavity coupling.

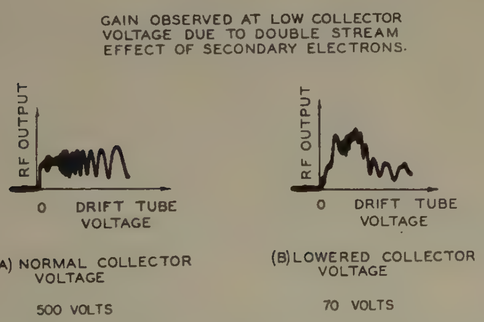


Fig. 10—Output voltage vs drift potential, illustrating gain obtained at lowered collector voltage.

Analysis was carried out to determine if the collector voltage, drift-tube voltage, and beam current were consistent with double-stream operation. Double-stream theory gives as the condition for maximum gain $(\omega_0/\omega)(v/\Delta v)=$a certain constant, where Δv is the difference of stream velocities. Here Δv would be approximately the collector voltage. This condition, written in terms of current and voltages, may be expressed at constant frequency as $IV^{3/2}_{\mathrm{Dr.\ tube}}/V^2_{\mathrm{collector}}$ = constant. Data taken at maximum gain are presented in Fig. 11. The curves should be a family of parabolas. Anomalies in the data were due to multiple peaks in the gain maximum, which were, in turn, due to improper focusing at certain voltages.

The large drift tube was replaced once more by the tapes, and measurements proved that while some double-stream interaction was present, at the same voltage as before, the smaller cross section did not allow secondaries to return as readily and gain was reduced to the order of several decibels.

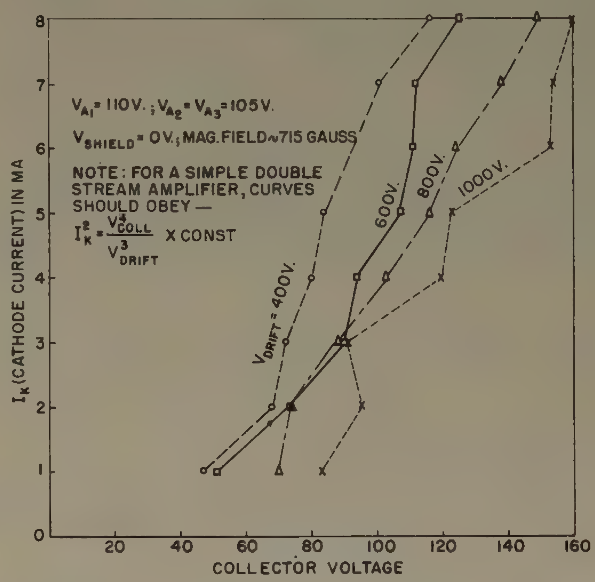


Fig. 11—Illustrating voltage and current conditions for maximum gain at lowered collector potential. Curves should be parabolic, to fit simple double-stream theory. Deviations near 3 and 5 ma are due to poor focusing.

While the experimental tube was operated in a manner which is typical of many beam-type tubes (confined flow, long-drift region, various drift-tube diameters), there are some established sources of gain which were not and could not have been observed. One of these is the growth of space-charge waves in a beam in perturbed Brillouin flow, as described by Bloom and Peter.[17] This phenomenon could not have occurred because the beam was always confined by a strong magnetic field, with flux through the cathode. Another mechanism for single-stream gain, first disclosed by Field, Tien, and Watkins[18,19] is the velocity-jump effect. This requires velocity changes of a certain type between the modulating and output cavities. Conditions in the measurements described never allowed any measurable gain of this type. A subsequent review of data taken by Haeff indicated that, in certain measurements, each of these phenomena could have resulted in the measured gain. There were also instances where it was possible that secondary electrons could have given double-stream gain similar to that produced by collector secondaries.

[17] R. S. Peter, S. Bloom, and J. A. Ruetz, "Space-charge wave amplification along an electron beam by periodic change of the beam impedance," *RCA Rev.*, vol. 15, pp. 113–120; March, 1954.

[18] L. M. Field, P. K. Tien, and D. A. Watkins, "Amplification by acceleration and deceleration of a single-velocity stream," Proc. I.R.E., vol. 39, p. 194; February, 1951.

[19] P. K. Tien and L. M. Field, "Space-charge waves in an accelerated electron stream for amplification of microwave signals," Proc. I.R.E., vol. 40, pp. 688–695; June, 1952.

Summary and Conclusions

Analysis of a ribbon-shaped electron beam, and numerical computation of the space-charge waves on a cylindrical beam, have proved that the spatial distribution of electrons of different velocity is not sufficient to alter the criterion for gain found for a homogeneous mixture of electrons of different velocity. While the theory is admittedly limited to certain simple types of velocity distribution, these seem representative of practical situations. The space-charge wave solutions for beams with space-charge depression of potential were found to vary little from those of a univelocity beam. Measurements made on a tube similar to that described by the numerical computations yielded no evidence of gain, supporting the theoretical findings. Under particular conditions of beam-focusing, it has been found that other mechanisms may give rise to gain: the presence of stray secondary electrons at appropriate velocity, the variations in beam diameter, or the existence of velocity changes in the interaction region.

Acknowledgment

The author wishes to thank Prof. J. Weber, University of Maryland, and Dr. L. Malter and many others at RCA Laboratories, whose advice and encouragement were of great aid. The numerical calculations were made possible by the co-operation of Dr. H. Goldstine of the Institute for Advanced Studies, Princeton, N. J., and were in part supported by a U. S. Army Ordnance Corps contract, held by the Institute.

RLC Lattice Transfer Functions*

A. D. FIALKOW† AND IRVING GERST‡

Summary—**Necessary and sufficient conditions that a real rational function be the transfer function of an RLC symmetric lattice are derived. The range of allowable values of the multiplicative factor (which determines the gain level) in the transfer function is determined and an algorithm for its calculation is given. While the zeros of the transfer function may be anywhere in the complex number plane, the poles must lie in the left-half plane or its boundary excluding the values 0 and ∞. However, at a pole of the transfer function on the pure imaginary axis, the function must satisfy certain further properties which are derived. In virtue of these latter conditions, it is found that there are realizable transfer functions which cannot be synthesized (even up to a multiplicative factor) by means of a symmetric lattice. These realizable transfer functions, which lie outside the symmetric lattice structure, always have some pure imaginary poles which do not satisfy our special conditions for lattice realizability. However, when all the conditions are met, a synthesis procedure for obtaining a corresponding lattice is given. The results are illustrated by an example.**

1. Introduction

In an earlier paper [5],[1] we have obtained a complete theory for the transfer function of the general two terminal-pair network, either grounded or ungrounded, containing resistance, capacitance and self-inductance but no mutual coupling. If one considers two terminal-pair networks with these elements having a particular configuration, then the transfer function has further distinctive properties which are characteristic of that structure. Because of the widespread use of the symmetric lattice in network theory, it is of interest to determine these characteristic properties for it. This is done in the present paper for the case of the open-circuit symmetric lattice driven by a zero impedance generator. However, the necessary conditions for lattice realizability developed below hold also in the case of a resistive source or a resistive load. Also, by a modification of the synthesis method given, it is usually possible to provide for either of these terminations.

We proceed to a statement of our principal result. As usual the transfer function $A(p)$ is defined as the ratio of steady-state output voltage to input voltage in the domain of the complex frequency variable p. Write

$$A(p) = KN/D \tag{1}$$

where $N = p^n + a_1p^{n-1} + \cdots + a_n$, $D = p^m + b_1p^{m-1} + \cdots + b_m$ are polynomials with real coefficients having no common factors, and K is a constant. It is known [5] that in order for $A(p)$ to be the transfer function of a general two terminal-pair network it is necessary that the poles of $A(p)$ be in the left-half plane[2] (l.h.p) or on its boundary excluding $p=0$ and $p=\infty$. Poles on the imaginary axis must be simple and have a pure imaginary residue. These then are also necessary conditions on the transfer function of a symmetric lattice. However, the

* Original manuscript received by the IRE, April 14, 1954; revised manuscript received, January 13, 1955.
† Polytechnic Institute of Brooklyn, N.Y.
‡ Control Instrument Co., Brooklyn, N.Y.
[1] Numbers in brackets refer to the bibliography at end of paper.

[2] In this paper the abbreviations l.h.p. and r.h.p. will be used to denote respectively the interior of the left-half and the right-half planes. Reference to the boundary of these half-planes, whenever required, will always be made explicitly.

following further condition on the zeros and poles is also necessary in the case of a symmetric lattice:

(*A*) *Define*

$$X_h = \mathrm{Re}\left\{j^h \frac{d}{dp}\left[\frac{1}{A}\right]\cdot\frac{d^h}{dp^h}\left[\frac{1}{A}\right]\right\}, \quad h = 2, 3, \cdots.$$

Then at each pure imaginary pole of $A(p)$ either all the values of X_h are zero or the first nonzero value of X_h occurs for h even and is negative.

As for the multiplicative constant K,

(*B*) *it is necessary that $-K_0 \leqq K \leqq K_0$ where the maximum gain constant K_0 is the smallest value of κ, $\kappa>0$, such that at least one of the equations $D-(\kappa+\epsilon)N=0$, $D+(\kappa+\epsilon)N=0$ has a zero in the right-half plane for all small positive ϵ.* An algorithm for the practical determination of K_0 is given in the proof. Conversely, *a function $A(p)$ satisfying all of the above conditions may be realized as the transfer function of a symmetric lattice.*

We find that our results are at variance in essential points with results obtained in papers by Kahal [6] and Weinberg [7][3] on the symmetric lattice. Reserving the detailed consideration of these matters for appropriate portions of the sequel, the following remarks may be made now. Kahal [6, p. 131) states that the transfer function of the general two terminal-pair network can always be realized to within a constant factor by the symmetrical lattice structure, while Weinberg [7, p. 427] states that he has realized any physically realizable RLC transfer function within a multiplicative constant by means of a symmetric lattice. Both of these statements are incorrect. (The same criticism applies to a recent abstract by Weinberg [8].)

It is found that there are physically realizable RLC transfer functions having some pure imaginary poles which cannot be realized by any symmetric lattice. As a simple counter-example, the physically realizable transfer function[4] $A(p)=K(p^2-0.5p+0.5)/(p^2+1)\cdot(p+1)$ cannot be synthesized as a symmetric lattice for any $K\neq 0$. For applying (*A*) above to this function, we find that at the pole $p=j$ of $A(p)$, $X_2(j)=64/K^2>0$. It therefore follows from (*A*) that this function is unrealizable by means of a symmetric lattice. Thus in so far as the transfer function is concerned, the symmetric lattice is limited as compared to the general two terminal-pair network not only in the maximum gain constant attainable (as was already noted in the RC-case [2, pp. 64–65; 4]) but also in the possible zero-pole combinations.

Coming to another matter, the lattice realization of a transfer function is often used as an intermediary in the practically desirable realization of this transfer function as a grounded network. We do not consider this conversion problem since it appears more natural and more general to synthesize the transfer function directly by means of a grounded network whenever this is theoretically possible as was done in [5]. Further, it does not seem to be generally realized that in order for the conversion process to succeed, it is necessary, at the very least, that the transfer function satisfy the conditions for a grounded network [5, p. 118] e.g., the zeros cannot be positive real. It is thus apparent that there are cases in which the conversion of the lattice into a grounded structure is impossible.

2. The Basic Theorem

Let $A(p)$ be given by (1). Without loss of generality, (by interchanging two terminals if necessary) we may assume $K>0$. The following theorem enables us to characterize $A(p)$ completely.

Theorem 1: Necessary and sufficient conditions for $A(p)=KN/D$ to be the transfer function of a symmetric lattice are that the equations $D-\kappa N=0$, $D+\kappa N=0$ have no roots in the r.h.p. for all $0<\kappa\leqq K$.

Proof: (*a*) *Necessity.* Suppose $A(p)$ as given by (1) is the transfer function of a symmetric lattice whose constituent impedances are Z_a and Z_b. Then we have

$$A(p) = \frac{KN}{D} = \frac{Z_b - Z_a}{Z_b + Z_a}. \tag{2}$$

If we replace Z_a and Z_b in the lattice by new impedances Z_a', Z_b' where

$$Z_a' = \left(\frac{1+\lambda}{2}\right)Z_a + \left(\frac{1-\lambda}{2}\right)Z_b$$

$$Z_b' = \left(\frac{1-\lambda}{2}\right)Z_a + \left(\frac{1+\lambda}{2}\right)Z_b,$$

with $0<\lambda\leqq 1$, we get a new transfer function $A_1(p)$ such that

$$A_1(p) = \frac{Z_b' - Z_a'}{Z_b' + Z_a'} = \frac{\lambda(Z_b - Z_a)}{Z_b + Z_a} = \lambda K\frac{N}{D}\cdot \tag{3}$$

Write $\kappa=\lambda K$ so that $0<\kappa\leqq K$. Then it follows from (3) that

$$\frac{D-\kappa N}{D+\kappa N} = \frac{Z_a'}{Z_b'}\cdot \tag{4}$$

Since the polynomials $D-\kappa N$ and $D+\kappa N$ can have no common zeros, we conclude from (4) that their zeros must lie in the l.h.p. or on its boundary.

(*b*) *Sufficiency.* Suppose now that both $D-\kappa N=0$ and $D+\kappa N=0$ have no zeros in the r.h.p. for $0<\kappa\leqq K$. We shall find constituent impedances, Z_a and Z_b of a lattice having KN/D as its transfer function. First we prove that the rational function

$$\psi(p) = \frac{D-KN}{D+KN} \tag{5}$$

cannot assume a negative real value in the r.h.p. For suppose a value $p=p_1$ exists with Re $[p_1]>0$ such that

[3] This paper is based on a chapter of [9] and was published on the recommendation of the I.R.E. Professional Group on Circuit Theory.

[4] Cf. [5, pp. 125–126] where this function with $K=2$ is synthesized as a grounded, two terminal-pair network. Using an alternative technique [5, p. 125] which is valid for sufficiently small K, this function with $K=2/3$ may be synthesized as a two terminal-pair network containing 8 elements.

$$\text{Re}\,[\psi(p_1)] < 0, \qquad \text{Im}\,[\psi(p_1)] = 0. \tag{6}$$

Now[5]

$$\text{Re}\,[\psi(p_1)] = \frac{|D(p_1)|^2 - K^2|N(p_1)|^2}{|D(p_1) + KN(p_1)|^2}, \tag{7}$$

$$\text{Im}\,[\psi(p_1)] = \frac{K}{j}\cdot\frac{[\overline{N}(p_1)D(p_1) - N(p_1)\overline{D}(p_1)]}{|D(p_1) + KN(p_1)|^2}. \tag{8}$$

Since $D(p_1)\neq 0$, it follows from (6) and (8) that $N(p_1)/D(p_1) = \overline{N}(p_1)/\overline{D}(p_1)$, which shows that $N(p_1)/D(p_1)$ is real. Hence from (6) and (7)

$$1 - K^2\left[\frac{N(p_1)}{D(p_1)}\right]^2 < 0.$$

But then for $\kappa = |D(p_1)/N(p_1)|$, the inequalities $0<\kappa<K$ hold, but we have $D^2(p_1) - \kappa^2 N^2(p_1) = 0$ which contradicts the first sentence of this paragraph. This proves that $\psi(p)$ cannot be negative real in the r.h.p.

We now make use of a theorem which we state here but whose proof is deferred until Appendix I.

Theorem 2: Let $F(p)$ be a real rational function which does not assume any negative real values in the r.h.p. and let $Z(p)$ be a positive real rational function such that $\text{Re}[ZF]\geq 0$ *on $p=j\omega$. Then ZF is a positive real function.*

In our application of this theorem we take F as ψ defined by (5) and we form a particular Z as follows: Let the imaginary part[6] of ψ on $p=j\omega$ be denoted by $V(\omega)$. Since $V(\omega)$ is an odd function of ω, it may be written in the form

$$V(\omega) = \epsilon\omega(\delta_1^2 - \omega^2)\cdots(\delta_r^2 - \omega^2)V'(\omega^2),$$

where $0, \pm\delta_1, \pm\delta_2, \cdots, \pm\delta_r$ are all the real zeros and poles of odd multiplicity of $V(\omega)$, arranged so that $0<\delta_1^2<\delta_2^2<\cdots<\delta_r^2$. Then ϵ may be chosen as either $+1$ or -1 such that $V'(\omega^2)\geq 0$ for all ω. Depending on whether $\epsilon=+1$ or -1, take Z respectively as $(p^2+\delta_1^2)\cdot(p^2+\delta_3^2)\cdots/p(p^2+\delta_2^2)\cdots$ or the reciprocal of this function. One may readily verify that $\text{Re}\,[Z\psi]\geq 0$ when $p=j\omega$ so that $Z\psi$ is a positive real function by Theorem 2. If the impedances of the lattice are now chosen as $Z_a = Z\psi$, $Z_b = Z$ then according to (2) and (5), the required transfer function KN/D is obtained. This completes the proof of Theorem 1.

The reactance Z which appears above was first defined by Kahal [6]. It is used here to wind up the proof of Theorem 1 in economical fashion. However its use may result in complicating the network realization by introducing certain redundant factors in Z_a. It may be shown (but we omit the proof here) that in general we may find Z_a and Z_b containing no redundant factors and neither one restricted to be a reactance such that $\psi = Z_a/Z_b$. By this means it is frequently possible to provide for a resistive source or a resistive load.

[5] A bar denotes the conjugate complex number.
[6] We assume that $V(\omega)\not\equiv 0$. The case in which $V(\omega)\equiv 0$ is considered in Appendix II.

3. The Zeros and Poles of Lattice Transfer Functions

All the properties characterizing the transfer function of the symmetric lattice which are listed in the introduction may be derived from Theorem 1. However, as some of these have already been established for general two terminal-pair networks in [5], we limit ourselves to deriving the remaining ones, (*A*) and (*B*) of the introduction, which apply specifically to the symmetric lattice. In this section, we prove (*A*) reserving the proof of (*B*) for the following section.

It follows from Theorem 1 that if $A(p) = KN/D$ is to be the transfer function of a lattice for some K (i.e. up to a multiplicative constant) then for all small κ, $\kappa>0$, no zero of either $D-\kappa N$ or $D+\kappa N$ can be in the r.h.p. If D is properly Hurwitz, then this follows automatically by continuity considerations; for any zero of D in the l.h.p. will vary into a zero of $D\pm\kappa N$ which is also in the l.h.p. if κ is small enough. However, if D has zeros on the imaginary axis a further investigation is required. This case is not considered by Weinberg [7], leading him to the error mentioned in the introduction.

Coming to the proof of (*A*), we consider a pure imaginary zero of D, $p=j\omega_0$, $\omega_0\neq 0$. Consider the equation $D(p)-\kappa N(p)=0$ which defines p implicitly as a function of κ. Since $p=j\omega_0$ is a simple root of this equation when $\kappa=0$, we may expand p as a power series in κ for sufficient small κ, of the form

$$p = j\omega_0 + \alpha_1\kappa + \alpha_2\kappa^2 + \cdots. \tag{9}$$

The corresponding root of $D(p)+\kappa N(p)=0$ has an expansion which is obtained from (9) by replacing κ by $-\kappa$. Hence we require that for all small real κ the right member of (9) have a nonpositive real part. Necessary and sufficient for this to occur are that either[7]

(*i*) $\text{Re}\,(\alpha_h)=0$ *for all h.*

(*ii*) *If α_h is the first coefficient in (9) whose real part is not zero, then h must be even and* $\text{Re}\,(\alpha_h)<0$.

It will be shown in Appendix III that these conditions (i), (ii) on the coefficients of (9) are equivalent to condition (*A*) of the Introduction. (See also the last sentence of the next section.)

In drawing the erroneous conclusion that $A(p)$ may always be realized by a lattice for sufficiently small K, Kahal [6, p. 132] incorrectly assumes that Im $[A(p)]$ in the neighborhood of $p=j\omega_0$ may always be approximated by the imaginary part of the first term in the Laurent expansion of $A(p)$. This error is equivalent to the supposition that the terms $\alpha_2\kappa^2+\alpha_3\kappa^3+\cdots$ of (9) may be ignored in our present discussion.

4. The Maximum Gain Constant

In this section, it is assumed that D and N meet the conditions for realizability with small K. We now consider the maximum gain constant K_0 which may be

[7] It may be shown that (*i*) obtains if and only if $A(p)$ is an even function of p, i.e. we are in the LC-case.

realized. This question did not arise in previous RLC lattice synthesis techniques which realize the transfer function up to a multiplicative constant.[8] While it simplifies the problem, this commonly used but artificial restriction sidesteps a basic question; for with transfer functions, unlike impedances, the level of response is an intrinsic quantity if transformers are excluded. An amplifier to boost the level may be unnecessary practically and in any case is a device which is alien to passive network theory.

According to Theorem 1, K_0 must have the property that $D-\kappa N$ and $D+\kappa N$ have no zeros in the r.h.p. for $0<\kappa\leqq K_0$, while at least one of $D-(K_0+\epsilon)N$, $D+(K_0+\epsilon)N$ has a zero in the r.h.p. for any ϵ sufficiently small and positive. This description of K_0 immediately suggests a way of determining it. For in order to pass from l.h.p. to r.h.p., the zeros of $D\pm\kappa N$ as κ increases positively, must first cross the imaginary axis. Hence K_0 must be one of the positive values of κ for which $D\pm\kappa N=0$ has some pure imaginary roots.

We assume now that we are not in the LC-case,[9] i.e., N/D is not an even function of p. If and only if this is so, there are just a finite number of values κ for which $D\pm\kappa N=0$ has pure imaginary roots. If $m=n$ in (1), then $p=\infty$ is a root of $D-\kappa N=0$ corresponding to $\kappa=1$. The values of κ which correspond to finite pure imaginary roots of $D\pm\kappa N=0$ are obtained by solving the simultaneous system

$$\begin{aligned} D_e \pm \kappa N_e &= 0 \\ D_0 \pm \kappa N_0 &= 0, \end{aligned} \tag{10}$$

where N_e, D_e and N_0, D_0 are respectively the even and odd power terms of N and D. One root of (10) is always $p=0$, which corresponds to the value[10] $\kappa=|b_m/a_n|$. From [5] we know that $K_0\leqq\text{Min}(1, |b_m/a_n|)$ if $m=n$ and $K_0\leqq|b_m/a_n|$ if $m>n$. Let $0<\kappa_1<\kappa_2<\cdots<\kappa_s$ be those solutions of the system (10) (if any such exist) for which $\kappa_s<\text{Min}(1, |b_m/a_n|)$ if $m=n$ and $\kappa_s<|b_m/a_n|$ if $m>n$. Starting with κ_1 and proceeding to each κ_i $(i=1, 2, \cdots, s)$ in turn, we must test to see whether any zeros of $D\pm(\kappa_i+\epsilon)N$ are in the r.h.p. for small positive ϵ. If κ_M is the first κ_i for which this occurs, then $K_0=\kappa_M$. If there are no κ_i with this property then $K_0=\text{Min}(1, |b_m/a_n|)$ if $m=n$ and $K_0=|b_m/a_n|$ if $n<m$.

To carry out the above test we need examine only the variation of the pure imaginary zeros of $D\pm\kappa_iN$ when κ_i is replaced by $\kappa_i+\epsilon$. For example, let $p=j\omega_a$ be a zero of $D-\kappa_aN$ where κ_a is one of the above κ_i, and where for $0<\kappa<\kappa_a$, all the zeros of $D\pm\kappa N$ have been in the l.h.p. (or its boundary). It follows using Lemma 1(*ii*) of Appendix I (applied to ψ of (5) with $K=\kappa_a$) that $p=j\omega_a$ can be either a simple zero or a double zero of $D-\kappa_aN$. Using (*vi*) of the same lemma it can be proved that *if $p=j\omega_a$ is a double zero of $D\pm\kappa_aN$, then κ_a must be κ_M* defined above.

Now consider the remaining case in which $p=j\omega_a$ is a simple zero of $D-\kappa_aN$. Then in a procedure similar to that used in the preceding section, we may expand the solution p of $D(p)-\kappa N(p)=0$ in the neighborhood of $p=j\omega_a$ as a Taylor series in $\kappa-\kappa_a$ of the form

$$p = j\omega_a + \alpha_1(\kappa-\kappa_a) + \alpha_2(\kappa-\kappa_a)^2 + \cdots. \tag{11}$$

Recalling that p is in the l.h.p. for $\kappa-\kappa_a$ small and negative, it follows that *p will be in the r.h.p. for $\kappa-\kappa_a$ small and positive if and only if the first coefficient α_h whose real part is not zero has h odd.*[11] The results of Appendix III may now be applied to express this condition directly in terms of the transfer function. It follows from (13) of this Appendix and the argument preceding (13) there, that if we define a sequence $W_h(h=1, 2, \cdots)$ where

$$W_h = \text{Re}\left\{\frac{d^h}{dp^h}\left[\frac{1}{A}\right]\right\}, \quad h \text{ odd};$$

$$W_h = \text{Im}\left\{\frac{d^h}{dp^h}\left[\frac{1}{A}\right]\right\}, \quad h \text{ even},$$

then *at least one root of $D-(\kappa_a+\epsilon)N=0$ will be in the r.h.p. if and only if the first nonzero value of $W_h(j\omega_a)$ occurs for h odd.* All of the above results apply equally well if $p=j\omega_a$ is a zero of $D+\kappa_aN$.

The preceding conditions for determining κ_M when $p=j\omega_a$ is a simple zero of $D\pm\kappa_aN$ are stated directly in terms of the transfer function. We now derive an alternate set of conditions in this case which are given indirectly, but whose use requires a minimum of computation. Let the series

$$\kappa = \kappa_a + \beta_1(p-j\omega_a) + \beta_2(p-j\omega_a)^2 + \cdots$$

be the inverse of (11), i.e., the expansion of $\kappa=D/N$ at $p=j\omega_a$. Then, when $p=j\omega$, we have

$$\text{Im}\left[\frac{D}{N}\right] = \text{Re}\,(\beta_1)(\omega-\omega_a) - \text{Im}\,(\beta_2)(\omega-\omega_a)^2 + \cdots.$$

Since

$$\beta_i = \frac{1}{i!}\left[\frac{d^i\kappa}{dp^i}\right]_{\kappa=\kappa_1},$$

(13) of Appendix III together with the above italicized conditions on the α_h may be used to show that if $\kappa_a\neq\kappa_M$ then ω_a is an even order zero of $\text{Im}\,[D/N]$. Since

$$\text{Im}\left[\frac{D}{N}\right]_{p=j\omega} = \frac{1}{i}\left[\frac{N_eD_0 - N_0D_e}{|N|^2}\right]_{p=j\omega},$$

[8] The maximum gain constant for RC lattice networks has been determined (Cf. [1; 3, p. 58]). On the other hand Weinberg's generalization [7, §3] of [1] for RLC lattice networks yields a constant which is not the true maximum gain constant K_0. Thus, for example, if $A(p)=K/(p^2+0.1p+1)$, then $K_0=1$, but the maximum value possible by Weinberg's method of §3 is $K=1/800$.

[9] For the determination of K_0 in the LC-case, see Appendix II.

[10] We assume here that a_n is different than zero. If $a_n=0$, the ratio b_m/a_n can be interpreted as ∞ in our results.

[11] The existence of a coefficient α_q with $\text{Re}\,(\alpha_q)\neq0$ is assured here. For if $\text{Re}\,(\alpha_i)=0$ for all i, then $A(p)$ is again an LC-transfer function which we have excluded from this discussion.

it follows that for $j\omega_a$ a simple zero of $D\pm\kappa_a N$, p of (11) will be in the r.h.p. for $\kappa-\kappa_a$ small and positive if and only if $j\omega_a$ is an odd order zero of the polynomial $N_eD_0-N_0D_e$.

Summarizing the preceding discussion we have the following procedure for determining K_0: (*a*) *Solve the system* (10) *for all pairs* ($p=j\omega_i$, $\kappa=\kappa_i$), ω_i *real and* $\neq 0$, $\kappa_i>0$. *By eliminating* κ *in* (10), *the values* $p=j\omega_i$ *may be determined first as the pure imaginary zeros of the polynomial* $Q=N_eD_0-N_0D_e$ *and the* κ_i *obtained subsequently by substituting in* (10). (*b*) *Denote by* κ_i' *those values of* κ_i *for which either* $p=j\omega_i$ *is a double root of* $D\pm\kappa N=0$ *or* $p=j\omega_i$ *is an odd order zero of* Q. (*c*) *Then* $K_0=\text{Min}\,[1, |b_m/a_n|, \kappa_i']$ *if* $n=m$ *or* $K_0=\text{Min}\,[|b_m/a_n|, \kappa_i']$ *if* $n<m$.

By employing an argument similar to the one just used, we can also show that condition (*A*) of the Introduction which was proved in the preceding section, may be replaced by the following condition which is simpler to apply computationally: Let $p=j\omega_0$ be a pole of N/D with residue $j\gamma$, γ real, $\neq 0$. Then for realizability we must have $[N_e(j\omega)D_0(j\omega)-N_0(j\omega)D_e(j\omega)]/j=a(\omega-\omega_0)^r+\cdots$, $a\neq 0$ with r even and $a\gamma<0$.

5. Example

The following example will serve to illustrate the foregoing procedure. Consider the realizable transfer function

$$A(p)=\frac{KN}{D}=K\left(p^3+\frac{5}{3}p^2+\frac{5}{3}p+1\right)\Big/\left(p^4+\frac{5}{4}p^3+\frac{11}{4}p^2+\frac{7}{4}p+\frac{5}{4}\right).$$

We first determine its maximum gain constant K_0, when it is synthesized as a symmetric lattice. The final criterion of the previous section for determining K_0 will be applied. Since here

$$Q=N_eD_0-N_0D_e=-p(p^2+\tfrac{1}{3})(p^2+1)^2,$$

we have the pure imaginary zeros $p=\pm j$ and $p=\pm j\sqrt{3}/3$ which may be verified to be simple zeros of $D-\kappa N$ for $\kappa=3/4$, $\kappa=1$ respectively. As just $p=\pm j\sqrt{3}/3$ are odd order zeros of Q(for $p\neq 0$), it follows that the only κ' is $\kappa'=1$. Hence, since $m=4>3=n$, $b_m=5/4$, $a_n=1$, we have $K_0=\text{Min}\,[5/4, 1]=1$.

The synthesis of $A(p)$ when $K=1$ may now be accomplished by the method following Theorem 2. For the function ψ given by (5) is here

$$\psi=\left(p^4+\frac{1}{4}p^3+\frac{13}{12}p^2+\frac{1}{12}p+\frac{1}{4}\right)\Big/\left(p^4+\frac{9}{4}p^3+\frac{53}{12}p^2+\frac{41}{12}p+\frac{9}{4}\right)=N_1/D_1.$$

Then we find that $V=\text{Im}\,[\psi(j\omega)]$ is

$$V=\frac{-2\omega(\frac{1}{3}-\omega^2)(1-\omega^2)^2}{|D_1(j\omega)|^2}=\epsilon\omega(\tfrac{1}{3}-\omega^2)V'(\omega^2),$$

where $\epsilon=-1$ and $V'(\omega^2)=(1-\omega^2)^2/|D_1(j\omega)|^2$. Hence

$$Z_b=Z=\frac{p}{p^2+\frac{1}{3}};$$

$$Z_a=Z\psi=\frac{p(p^2+\frac{1}{4}p+\frac{3}{4})}{p^4+\frac{9}{4}p^3+\frac{53}{12}p^2+\frac{41}{12}p+\frac{9}{4}}.$$

Appendix I

Proof of Theorem 2

We require two preliminary lemmas for the proof of Theorem 2.

Lemma 1: Let $F(p)$ *be a real rational function which does not assume any negative real value in the r.h.p. Further let* $U(\omega)$ *and* $V(\omega)$ *denote respectively the real and imaginary parts of* F *on the imaginary axis* $p=j\omega$. *Then* F, U *and* V *enjoy the following properties*:

(*i*) F *is analytic in the r.h.p. and has no zeros there.*

(*ii*) *On the imaginary axis* $p=j\omega$, F *can have at most second order zeros and poles.*

The remaining properties all concern the behavior of F, U and V at a point $p=p_0=j\omega_0$ on the imaginary axis, the indicated expansions being the Laurent expansions at this point.

(*iii*) *If* $F=a+\cdots$, $V=a_2(\omega-\omega_0)^{2q+1}+\cdots$, where $aa_2\neq 0$, $q\geq 0$, then $a>0$.

(*iv*) *If* $F=a(p-p_0)+\cdots$, $V=a_2(\omega-\omega_0)^{2q+1}+\cdots$, *where* $aa_2\neq 0$, $q\geq 0$, *then* $a_2>0$.

(*iv*)′ *If* $F=a/(p-p_0)+\cdots$, $V=a_2(\omega-\omega_0)^{2q-1}+\cdots$, *where* $aa_2\neq 0$, $q\geq 0$, *then* $a_2<0$.

(*v*) *If* $F=a(p-p_0)+\cdots$, $V=a_2(\omega-\omega_0)^{2q}+\cdots$, *where* $aa_2\neq 0$, $q\geq 1$, *then* $U=a_1(\omega-\omega_0)+\cdots$ *with* $a_1a_2<0$.

(*v*)′ *If* $F=a/(p-p_0)+\cdots$, $V=a_2(\omega-\omega_0)^{2q}+\cdots$, *where* $aa_2\neq 0$, $q\geq 0$, *then* $U=a_1/(\omega-\omega_0)+\cdots$, *with* $a_1a_2>0$.

(*vi*) *If* $F=a(p-p_0)^2+\cdots$, *where* $a\neq 0$ *and* $V(\omega)\neq 0$, *then* $a>0$ *and* $V=a_2(\omega-\omega_0)^{2q+1}+\cdots$, *with* $a_2>0$, $q\geq 1$.

(*vi*)′ *If* $F=a/(p-p_0)^2+\cdots$, *where* $a\neq 0$ *and* $V(\omega)\neq 0$, *then* $a>0$ *and* $V=a_2(\omega-\omega_0)^{2q-1}+\cdots$, *with* $a_2<0$, $q\geq 0$.

Remarks: This same subject has already been studied by Kahal [6, Appendix I]. In his discussion, (*i*) is incorporated as part of the definition of F, (*ii*) is stated and proved, (*iii*) and part of (*vi*) are stated without complete proof. In place of (*iv*) and (*v*), he attempts to prove a result [6, p. 132] which we may paraphrase as follows: "If $F=a(p-p_0)+\cdots$, $V=a_2(\omega-\omega_0)^q+\cdots$, where $aa_2\neq 0$, then either $q=1$ and $a_2>0$, or else q is even." The latter conclusion is false as may be seen by taking F equal to the product Z_1Z_2 where Z_1 is a reactance function such that $Z_1(j\omega)=jX_1(\omega)$, $X_1(\omega_0)=0$, and Z_2 is an impedance function such that $Z_2(j\omega)=R_2(\omega)+jX_2(\omega)$, $R_2(\omega_0)=0$, $X_2(\omega_0)\neq 0$. Then $V=R_2(\omega)X_1(\omega)$ has an odd order zero of at least third order at $\omega=\omega_0$. For example, let $Z_1=(p^2+1)/p$, $Z_2=(2p^2+p+1)/(p^2+p+2)$

and consider $p=j$. This mistake vitiates Kahal's proof for the synthesis of a lattice when $F=\psi(p)$ defined by (5) has simple zeros or poles on the boundary.

Proof: It suffices to prove the above properties as regards the zeros of F. The statements about the poles then follow by considering $1/F$ which again assumes no negative real value in the r.h.p. Our proof will depend upon the following well-known mapping property of analytic functions:

(*M*) *Let $z=f(p)$ be analytic at $p=p_0$, and have the expansion*

$$z = z_0 + c(p - p_0)^t + \cdots, \qquad c \neq 0,\ t \geqq 1$$

there. Then the map of the sector S: $\theta_1 \leqq \text{arc } (p-p_0) \leqq \theta_2$ for p in the neighborhood of p_0, will completely cover a curvilinear sector S': $\phi_1 \leqq \text{arc } (z-z_0) \leqq \phi_2$ for $|z-z_0|$ sufficiently small. If α and β designate the rays arc $a=\theta_1$, arc $\beta=\theta_2$ and if α' and β' are respectively the maps of α and β, then ϕ_1 and ϕ_2 are the variable angles given by $\phi_1=\text{arc } \alpha'$, $\phi_2=\text{arc } \beta'$. Furthermore, the angle between β' and α' at $z=z_0$ is $t(\theta_2-\theta_1)$.

We now proceed to prove the various statements of the lemma seriatim. If now F were zero at $p=p_i$ in the r.h.p. then by (*M*) with $f(p)=F(p)$, $\theta_1=0$, $\theta_2=2\pi$, the map of a neighborhood of p_1 would cover a neighborhood of the origin in the z-plane. Thus for some point in the r.h.p. F would be negative real which is a contradiction. This proves (*i*).

In proving the remaining properties we shall apply (*M*) with $f=F$ and with S as a semi-circular neighborhood $-\pi/2 \leqq \text{arc } (p-p_0) \leqq \pi/2$, so that α and β are respectively the lower and upper halves of the imaginary axis. Suppose now contrary to (*ii*) that F has a zero of order t, $t \geqq 3$ at $p=j\omega_0$. Then the curvilinear sector S' will have an angle of $t\pi \geqq 3\pi$ at $z=0$, and thus surely contains negative real points. This contradiction proves (*ii*).

To prove (*iii*) suppose $a<0$. Then in view of the expansion of V one of α' and β' will be in the upper half z-plane and the other in the lower half z-plane. Thus S' certainly contains a part of the negative real axis which is a contradiction.

Similarly if a_2 were negative in (*iv*), then α' would be in the upper half-plane and β' in the lower half-plane, so that S' again would include negative real points. This contradiction proves (*iv*).

To prove (*v*) suppose that $a_1a_2>0$. Then it follows from the expansions of U and V that either α' is in the second quadrant and β' is in the first quadrant; or α' is in the fourth quadrant and β' is in the third quadrant. Either of these choices results in S' containing a negative real segment which is a contradiction.

Finally suppose in (*vi*) that $V=a_2'(\omega-\omega_0)^{2q}+\cdots$, $a_2'\neq 0$, $q\geqq 1$. Then α' and β' would both be in the upper half-plane or the lower half-plane (depending on the sign of a_2'). Since t in (*M*) is 2 here, the angle of S' is 2π. Thus S' must include a segment of the negative real axis. Hence ω_0 cannot be an even order zero of V and we have $V=a_2(\omega-\omega_0)^{2q+1}+\cdots$, $a_2\neq 0$, $q\geqq 1$, and a is real. By using the argument of (*iv*), a_2 must be positive. If now $a<0$, then $U=-a(\omega-\omega_0)^2+\cdots$, and it follows that α' is in the fourth quadrant while β' is in the first quadrant. This again leads to a contradiction and the proof of the lemma is complete.

Lemma 2: Let $G(p)$ be a real rational function such that Re $[G(p)]\geqq 0$ *on $p=j\omega$. Then at a pole $p=p_0=j\omega_0$ of $G(p)$ of the first or second order respectively the following expansions hold.*

(*i*) $G(p)=c/(p-p_0)+\cdots$, *c real*;
(*ii*) $G(p)=(c+dj)/(p-p_0)^2+\cdots$, $c\leqq 0$, *d real.*

Proof: *Suppose* $G(p)=(c+dj)/(p-p_0)^q+\cdots$, $q=1, 2$, where c and d are real. Then for $p=j\omega$

$$\text{Re } [G(p)] = \frac{\text{Re } [j^{-q}(c+dj)]}{(\omega-\omega_0)^q} + \cdots.$$

If $q=1$ then $d=0$, otherwise the real part will assume both positive and negative values in the neighborhood of ω_0. If $q=2$, Re $[j^{-2}(c+dj)]=-c\geqq 0$, to have Re $[G(p)]\geqq 0$. This establishes Lemma 2.

We now consider the proof of Theorem 2. Let u, U and v, V denote respectively the real and imaginary parts of Z and F for $p=j\omega$. Since Re $[ZF]\geqq 0$ on $p=j\omega$ and ZF is analytic in the r.h.p. by Lemma 1 (*i*), we must show that on $p=j\omega$, ZF has at most poles of first order with positive residues. By Lemma 1 (*ii*) and the fact that Z is positive real, the orders of ZF, Z and F at a possible singularity $p=p_0=j\omega_0$ of ZF may be listed as follows:

	ZF	Z	F
(α_1)	-1	$+1$	-2
(α_2)	-1	0	-1
(α_3)	-1	-1	0
(β_1)	-2	0	-2
(β_2)	-2	-1	-1
(γ)	-3	-1	-2

To establish Theorem 2, we will show that cases β_1, β_2, γ are impossible while in cases α_1, α_2, α_3, the residue of the pole of ZF is positive.

Case (α_1): Here

$$Z=b(p-p_0)+\cdots,\ b>0; \qquad F=a/(p-p_0)^2+\cdots,\ a>0$$

by Lemma 1 (*vi*)′ and the result is immediate.

Case (α_2): Write

$$Z = b_1 + b_2 j + \cdots,\ b_1 \geqq 0,\ b_2 \text{ real},\ b_1^2 + b_2^2 \neq 0;$$

$$F = \frac{a_2 + a_1 j}{p - p_0} + \cdots,\ a_2 \geqq 0,\ a_1 \text{ real},\ a_1^2 + a_2^2 \neq 0,$$

where Lemma 1 (*iv*)′ has been used to establish the sign of a_2. Then

$$ZF = \frac{(a_2b_1 - a_1b_2) + (a_1b_1 + a_2b_2)j}{p - p_0} + \cdots.$$

Hence by Lemma 2 (*i*) with $G=ZF$,

$$a_1b_1 + a_2b_2 = 0. \tag{12}$$

If $b_1a_2\neq 0$ then we may use (12) to write the residue

$$a_2b_1 - a_1b_2 = a_2b_1 + \frac{a_1^2b_1}{a_2},$$

which shows the residue at $p=p_0$ is positive. If $b_1=0$ then by (12) $a_2=0$ and conversely. But then $a_1b_2\neq 0$. Now $\mathrm{Re}_{p=j\omega}[ZF]=uU-vV$. We have $u=b_3(\omega-\omega_0)^{2k}+\cdots$, $b_3>0$, $k\geqq 1$, $V=a_3(\omega-\omega_0)^s+\cdots$, $a_3\neq 0$. $s\geqq 0$. Hence

$$\begin{aligned}\mathrm{Re}_{(p=j\omega)}[ZF] &= a_1b_3(\omega-\omega_0)^{2k-1}+\cdots\\ &\quad - a_3b_2(\omega-\omega_0)^s+\cdots.\end{aligned}$$

If s is odd then Re $[ZF]\geqq 0$ requires that $s=2k-1$ and $a_1b_3-a_3b_2=0$. But then by Lemma 1 *(iv)*$'$ $a_3<0$, and the residue $-a_1b_2=-a_3b_2^2/b_3>0$. If s is even then $s<2k-1$ and we must have $-a_3b_2>0$. By Lemma 1 *(v)*$'$, $a_1a_3>0$. Hence $-a_1b_2>0$. Thus in every case ZF has a positive residue.

Case (α_3): Let

$$Z = b/(p-p_0)+\cdots,\ b>0; \qquad F = a_1 + a_2j + \cdots.$$

Then

$$ZF = (a_1b + a_2bj)/(p-p_0)+\cdots,$$

and as in the preceding case we conclude that $a_2b=0$, which implies that $a_2=0$. If V has an odd order zero at $\omega=\omega_0$ then by Lemma 1 *(iii)*, $a_1>0$ and the residue $a_1b>0$. If $V=a_3(\omega-\omega_0)^{2q}+\cdots$, $a_3\neq 0$, $q\geqq 0$ and writing $u=b_1(\omega-\omega_0)^{2k}+\cdots$, $b_1>0$, $k\geqq 0$ then

$$\begin{aligned}\mathrm{Re}_{(p=j\omega)}[ZF] &= a_1b_1(\omega-\omega_0)^{2k}+\cdots\\ &\quad + a_3b(\omega-\omega_0)^{2q-1}+\cdots.\end{aligned}$$

We must have $2k<2q-1$ and $a_1b_1>0$ otherwise Re $[ZF]\ngeqq 0$. Thus $a_1>0$ and again the residue $a_1b>0$.

Case (β_1): We can write, using Lemma 1*(vi)*$'$

$$Z = b_1 + b_2j + \cdots,\ b_1\geqq 0,\ b_2 \text{ real},\ b_1^2+b_2^2\neq 0;$$

$$F = \frac{a}{(p-p_0)^2}+\cdots,\ a>0.$$

Then

$$ZF = (ab_1 + ab_2j)/(p-p_0)^2+\cdots,$$

and the use of Lemma 2*(ii)* leads to $ab_1\leqq 0$. This implies $b_1=0, b_2\neq 0$. By Lemma 1*(vi)*$'$ we have $V=a_2(\omega-\omega_0)^{2q-1}+\cdots$, $q\geqq 0$, $a_2<0$. If $u=b_3(\omega-\omega_0)^{2k}+\cdots$, $b_3>0$, $k\geqq 1$ then

$$\begin{aligned}\mathrm{Re}_{(p=j\omega)}[ZF] &= -ab_3(\omega-\omega_0)^{2k-2}+\cdots\\ &\quad - a_2b_2(\omega-\omega_0)^{2q-1}+\cdots.\end{aligned}$$

We must have $2k-2<2q-1$ and $-ab_3>0$. Thus case (β_1) is impossible

Case (β_2): Here, using Lemma 1*(iv)*$'$

$$Z = \frac{b}{p-p_0}+\cdots,\ b>0;$$

$$F \doteq \frac{a_2+a_1j}{p-p_0}+\cdots,\ a_2\geqq 0,\ a_1 \text{ real},\ a_1^2+a_2^2\neq 0;$$

$$ZF = \frac{ba_2+ba_1j}{(p-p_0)^2}+\cdots.$$

As in the preceding case, $ba_2\leqq 0$ which implies $a_2=0$, $a_1\neq 0$. Let

$$V = a_3(\omega-\omega_0)^s+\cdots,\quad a_3\neq 0,\ s\geqq 0;$$

$$u = b_1(\omega-\omega_0)^{2k}+\cdots,\ b_1>0,\ k\geqq 0.$$

Then

$$\begin{aligned}\mathrm{Re}_{(p=j\omega)}[ZF] &= a_1b_1(\omega-\omega_0)^{2k-1}+\cdots\\ &\quad + a_3b(\omega-\omega_0)^{s-1}+\cdots.\end{aligned}$$

If s is odd then $s-1<2k-1$ and $a_3b>0$. This is impossible, for by Lemma 1*(iv)*$'$, $a_3<0$. If s is even, then we must have $s-1=2k-1$ and $a_1b_1+a_3b=0$. Again this is impossible, for by Lemma 1*(v)*$'$, $a_1a_3>0$.

Case (γ): By Lemma 1*(vi)*$'$, $Z=b/(p-p_0)+\cdots$, $b>0$; $F=a/(p-p_0)^2+\cdots$, $a>0$.

Let $u=b_1(\omega-\omega_0)^{2k}+\cdots$, $b_1>0$, $k\geqq 0$. By Lemma 1*(vi)*$'$, $V=a_2(\omega-\omega_0)^{2q-1}+\cdots$, $a_2<0$, $q\geqq 0$ so that

$$\begin{aligned}\mathrm{Re}_{(p=j\omega)}[ZF] &= -ab_1(\omega-\omega_0)^{2k-2}+\cdots\\ &\quad + a_2b(\omega-\omega_0)^{2q-2}+\cdots.\end{aligned}$$

This is impossible since both $-ab_1$ and a_2b are negative. Thus all the pure imaginary poles of ZF are simple and have positive residues. This completes the proof of Theorem 2.

Appendix II

LC Lattice Transfer Functions

Suppose $\mathrm{Im}[\psi(j\omega)]\equiv 0$. Then using (8) with p_1 replaced by $j\omega$ we have $N(j\omega)/D(j\omega)\equiv\overline{N}(j\omega)/\overline{D}(j\omega)$ which implies that N/D is an even function of p. Thus $A=KN/D$ with N and D even polynomials, and where the zeros of D are pure imaginary and distinct. Hence A is an LC transfer function. The results for this case follow by paraphrasing the discussion of the RC case given in [3]. By using an argument similar to that in [3, pp. 56–58] with p replaced by p^2, it follows that if $D\pm\kappa N$ has no zeros in the r.h.p. for $0<\kappa\leqq K$ then

$$\psi = \frac{D-\kappa N}{D+\kappa N} = \eta\frac{(p^2+\zeta_1^2)(p^2+\zeta_2^2)\cdots}{(p^2+\xi_1^2)(p^2+\xi_2^2)\cdots},\quad \eta>0,$$

where the ξ_i^2 and ζ_i^2 are non-negative, and the combined sequence[12] of ξ_i^2 and ζ_i^2 arranged in ascending order

[12] Kahal's statement [6, p. 124] of the order relations of the zeros and poles of ψ is weaker than the one given here and is insufficient to accomplish the factorization of ψ into reactance functions Z_a and Z_b despite his statement to the contrary. For example the function $(p^2+1)(p^2+2)/(p^2+3)(p^2+4)$ satisfies his order conditions but may not be factored as Z_a/Z_b.

of magnitude consists of consecutive pairs (ξ_i^2, ζ_i^2) or (ζ_i^2, ξ_i^2) which may occur in either order, except that the last term in the sequence may be an unpaired ζ^2 or ξ^2. We may now choose[13]

$$Z_a = \lambda_1 p \frac{(p^2+\zeta_2^2)}{(p^2+\xi_1^2)} \cdot \frac{(p^2+\zeta_4^2)}{(p^2+\xi_3^2)} \cdot \cdots, \quad \lambda_1 > 0;$$

$$Z_b = \lambda_2 p \frac{(p^2+\xi_2^2)}{(p^2+\zeta_1^2)} \cdot \frac{(p^2+\xi_4^2)}{(p^2+\zeta_3^2)} \cdot \cdots, \quad \lambda_2 > 0,$$

with $\lambda_1\lambda_2 = \eta$, as the required lattice impedances in (2).

The maximum gain K_0 is given [3, pp. 58, 72–73] as

$$K_0 = \mathrm{Min}\,[1, |b_m/a_n|, K_d], \quad n = m$$
$$= \mathrm{Min}\,[|b_m/a_n|, K_d], \quad n < m.$$

Here K_d is the smallest numerical value of κ for which the equation $D-\kappa N=0$ has a multiple root. This means that K_d is the real root of smallest absolute value (if it exists) of the equation in κ obtained by equating the discriminant of $D-\kappa N$ to zero.

Appendix III

The Pure Imaginary Roots of $D(p)-\kappa N(p)=0$

In §3 and §4 we were led to the consideration of the pure imaginary roots of $D(p)-\kappa N(p)=0$ with $\kappa=0$ and $\kappa=\kappa_a$ respectively. In this Appendix, we investigate these roots in detail and obtain the results which were used in these earlier sections. Let

$$p = j\omega_0 + \alpha_1(\kappa-\kappa_0) + \alpha_2(\kappa-\kappa_0)^2 + \cdots, \quad \alpha_1 \neq 0,$$

be a solution of the equation $D(p)-\kappa N(p)=0$ for κ in the neighborhood of κ_0. The above equation corresponds to (9) if κ_0 is chosen as $\kappa_0=0$ or to (11) if $\kappa_0=\kappa_a$. The coefficients α_h are given by

$$\alpha_h = \frac{1}{h!}\left[\frac{d^h p}{d\kappa^h}\right]_{\kappa=\kappa_0}.$$

Write κ_h for $d^h\kappa/dp^h (h=1, 2, \cdots)$. Then we have

$$\frac{dp}{d\kappa} = \frac{1}{\kappa_1}, \qquad \frac{d^2p}{d\kappa^2} = -\frac{\kappa_2}{\kappa_1^3},$$

$$\frac{d^3p}{d\kappa^3} = -\frac{(\kappa_3\kappa_1 - 3\kappa_2^2)}{\kappa_1^5}, \cdots.$$

Thus $\mathrm{Re}\,[\alpha_1] = \mathrm{Re}\,[1/\kappa_1(j\omega_0)]$. If $\kappa_0=0$ (as in §3) then it follows from the fact that the residue of N/D at $p=j\omega_0$ is pure imaginary that $\kappa_1(j\omega_0)$ is pure imaginary and hence $\mathrm{Re}\,[\alpha_1]=0$. For other values of κ_0 this need not be so. However, in the case that $\mathrm{Re}\,[\alpha_1]=0$, we suppose now that $\mathrm{Re}[\alpha_1]=\mathrm{Re}[\alpha_2]=\cdots=\mathrm{Re}\,[\alpha_{r-1}]=0$, $\mathrm{Re}\,[\alpha_r]\neq 0$, $r\geqq 2$. Then it follows from the above equations that if $r=2$, $\mathrm{Re}\,[\alpha_2]=\mathrm{Re}\,[-\kappa_2(j\omega_0)/\kappa_1^3(j\omega_0)]/2!$; if $r=3$, then $\mathrm{Im}[\kappa_2(j\omega_0)]=0$, $\mathrm{Re}[\alpha_3]=\mathrm{Re}\,[-\kappa_3(j\omega_0)/\kappa_1^4(j\omega_0)]/3!, \cdots$.

In general, it may be shown using mathematical induction that if $1\leqq h<r$ then $\mathrm{Re}\,[\kappa_h(j\omega_0)]=0$ for h odd, $\mathrm{Im}\,[\kappa_h(j\omega_0)]=0$ for h even, and

$$\mathrm{Re}\,[\alpha_r] = \mathrm{Re}\,[-\kappa_r(j\omega_0)/\kappa_1^{r+1}(j\omega_0)]/r!.$$

Hence writing

$$X_h' = \mathrm{Re}\,[j^h\kappa_1(j\omega_0)\kappa_h(j\omega_0)], \quad (h = 2, 3, \cdots)$$
$$\kappa_1(j\omega_0) = j\beta \neq 0,$$

β real, we conclude that

$$\begin{aligned} &\mathrm{Re}\,[\alpha_1] = 0, \\ &\mathrm{Re}\,[\alpha_h] = X_h' = 0 \quad (h = 2, 3, \cdots, r-1) \\ &\mathrm{Re}\,[\alpha_r] = \frac{(-1)^r}{\beta^{r+2} r!} X_r'. \end{aligned} \tag{13}$$

We may use these equations to complete the proof of (A) of the introduction. Since $\mathrm{Re}\,[\alpha_r]\neq 0$, this is also true of X_r'. Furthermore if r is even, then $\mathrm{Re}\,[\alpha_r]$ and X_r' have the same sign. Thus we may use X_h' in place of $\mathrm{Re}\,[\alpha_h]$ in (i) and (ii) of the italicized sentence of §3. Also, since $\kappa=D/N=K/A$, we may replace κ in X_h' by $\kappa/K=1/A$ to get X_h defined in the introduction, as this merely multiplies X_h' by the positive constant $1/K^2$. This completes the proof of (A) in the introduction.

[13] There are other choices for Z_a and Z_b as follows from the fact that the discussion in [3, p. 55] for the RC case may be made to apply here also.

Bibliography

1. Bower, J. L., and Ordung, P. F., "The Synthesis of Resistor-Capacitor Networks." Proc. I.R.E., Vol. 38 (March, 1950), pp. 263–269.
2. Fialkow, A., "Two Terminal-Pair Networks Containing Two Kinds of Elements Only." *Proc. Symposium on Modern Network Synthesis*, Polytechnic Institute of Brooklyn, (1952), pp. 50–65.
3. Fialkow, A., and Gerst, I., "The Transfer Function of an RC Ladder Network." *Jour. Math. Phys.*, Vol. 30 (July, 1951), pp. 49–72.
4. Fialkow, A., and Gerst, I., "The Transfer Function of General Two Terminal-Pair RC Networks." *Quart. Appl. Math.*, Vol. 10, July, 1952), pp. 113–127.
5. Fialkow, A., and Gerst, I., "The Transfer Function of Networks Without Mutual Reactance." *Quart. Appl. Math.*, Vol. 12 (July, 1954), pp. 117–131.
6. Kahal, R., "Synthesis of the Transfer Function of Two Terminal-Pair Networks." *Trans. IEE*, Vol. 71, Part I (1952), pp. 129–134.
7. Weinberg, L., "A General RLC Synthesis Procedure." Proc. I.R.E., vol. 42 (February. 1954), pp. 427–437.
8. Weinberg, L., "Networks Terminated in Resistance at both Input and Output," Proc. I.R.E., Vol. 42 (March, 1954), p. 625.
9. Weinberg, L., *New Synthesis Procedure for Realizing Transfer Functions of RLC and RC Networks*. Tech. Rep. No. 201, Res. Lab. of Electronics, Mass. Inst. Tech., 1951.

Modes and Operating Voltages of Interdigital Magnetrons*

AMARJIT SINGH†

Summary—Methods have been discussed for obtaining a desirable frequency spectrum of the modes of an interdigital resonator, so that it may be possible to get useful operation in more than one mode. The consequences of phase reversal at certain locations in the anode, in the case of nonzero order modes, have been analyzed, together with the effects of phase-shifting fingers. Experimental results have been given, which are seen to be in substantial agreement with theory.

Introduction

The resonance frequencies as well as Q values of modes of various orders in interdigital magnetrons have been studied theoretically as well as experimentally.[1-4] The frequency spectrum is characterized by the fact that the modes of various orders are well separated from one another. In particular, the zero-order mode can be operated without the use of any additional mode control devices, such as straps. However, efficient operation in this mode requires the use of decoupling chokes.[5] Such chokes are not needed in the case of nonzero-order modes, as the latter do not couple strongly with a symmetrically located cathode. On the other hand, these modes occur in degenerate pairs, and also have points of phase reversal around the anode.

Because of these disadvantages of nonzero-order modes, most of the work on operating interdigital magnetrons has been done in the zero-order mode.[6-9] Typical results which have been reported in this mode include a cw power output of 500 watts or a peak power output of 300 kilowatts at frequencies of the order of 2,500 mc/sec. and over-all efficiencies up to 70 per cent. This mode has also been used in an inverted magnetron,[10] giving 1,500 watts at 5 per cent duty ratio, with an over-all efficiency up to 50 per cent. However if the problems of degeneracy and phase reversal in the case of nonzero-order modes can be solved satisfactorily, then an interdigital magnetron offers the possibility of useful operation at more than one frequency. With tunable tubes having overlapping tuning ranges for various modes, wide tuning ranges would also be possible. Apart from this, nonzero-order modes can give higher frequencies for the same dimensions of the resonator. Interest in a nonzero-order mode has been shown in another paper[11] also, dealing with the design of a waveguide loaded interdigital resonator for operation in the second-order mode.

In order to remove the degeneracy between the two first-order modes, Crawford and Hare used two capacitive fingers behind the main set of fingers. Also, in order to make the "polarity of the fingers alternate regularly all the way around the anode." they used the "phase reversing anode."[12] At each position of zero E-field, two adjacent fingers were joined to the same side of the cavity. The two could be made as one broad finger, called a phase-shifting finger. Crawford and Hare obtained a cw power output of 50 watts at an efficiency of 40 to 50 per cent in the wavelength range of 6 to 12 centimeters.

In the work reported here, problems relating to the frequency spectrum of the interdigital magnetron, and to its operation in nonzero-order modes, have been investigated further. The results of an experimental study for correlating the frequencies of various modes with resonator parameters have been given. Methods have been discussed for removing the degeneracy of nonzero-order modes, and making all the resultant modes equally spaced in frequency.

Experimental evidence and theoretical justification for the excitation of each of the nonzero-order modes at more than one voltage have been given. It has been found that phase-shifting fingers do not ensure operation at only one voltage for one mode. An alternative approach to this problem has been suggested.

Modes of a Simple Interdigital Resonator

In order to control the frequency spectrum of an interdigital resonator, it is first of all desirable to know the general manner in which the modes of various or-

* Original manuscript received by the IRE, March 30, 1954; revised manuscript received January 4, 1955. This work was supported jointly by the U. S. Navy (Office of Naval Research), the U. S. Army Signal Corps and the U. S. Air Force; Contract N5 ORI-76 Task 1, Harvard University.

† National Physical Laboratory of India, New Delhi, India.

[1] F. H. Crawford and N. D. Hare, "A tunable squirrel-cage magnetron—the donutron," Proc. I.R.E., vol. 35, pp. 361–369; April, 1947.

[2] J. F. Hull and L. W. Greenwald, "Modes in interdigital magnetron," Proc. I.R.E., vol. 37, pp. 1258–1263; November, 1949.

[3] W. S. Lucke, "Obstacle Loaded Cylindrical Cavities with Application to the Interdigital Magnetron," Cruft Laboratory Technical Report No. 60, Harvard University; November, 1948.

[4] A. Leblond, "Study of an interdigital line used as an anode circuit of a magnetron oscillator for U.H.F.," *Ann. Radioélect.*, vol. 8, pp. 194–210; July, 1953.

[5] J. F. Hull and A. W. Randalls, "High-power interdigital magnetrons," Proc. I.R.E., vol. 36, pp. 1357–1363; November, 1948.

[6] *Ibid.*

[7] H. W. Welch, Jr. and G. R. Brewer, "Operation of Interdigital Magnetrons in Zero Order Mode," Technical Report No. 2, Electron Tube Laboratory, University of Michigan.

[8] F. Ludi, "Single cavity magnetron," *Tijdschr. ned. Radiogenoot.*, vol. 18, pp. 89–103; March 1953. Also F. Ludi, Proc. I.R.E., vol. 41, p. 799; June, 1953.

[9] A. Leblond; O. Doehler and R. Warnecke, " A new magnetron oscillator with interdigital circuit," *C. R. Acad. Sci. Paris*, vol. 236, pp 55–57; 5th Jan., 1953.

[10] J. F. Hull, "Inverted magnetron," Proc. I.R.E., vol. 40, pp. 1038–1041; September, 1952.

[11] G. Hok, "Design of waveguide loaded resonator for magnetron with interdigital circuit," Proc. I.R.E., vol. 41, pp. 763–769; June, 1953.

[12] Crawford and Hare, *op. cit.*

ders are influenced by the parameters of the fingers and the cavity. With this in view, a demountable resonator was designed, so that several combinations of anode and cavity parameters were easily obtainable. Fig. 1 shows a cross section of the resonator, the lower set of fingers being omitted for the sake of clarity. The cavity was formed by clamping two face plates F against a thick annular disc D. Fingers attached to two cylinders were inserted through holes in the face plates. The squirrel cage formed by the fingers was made coaxial with the annular disc by fitting the face plates and the disc into an outer cylinder C. Two caps completed the resonator. The resonance frequencies were determined by inserting two coupling loops into the cavity, one for feeding in power from a test oscillator, and the other for detecting the amplitude of oscillations. The modes were identified by plotting the field patterns with the help of a rotating probe. The rectified and amplified output of the probe was fed to a recording milliammeter, while the probe was slowly rotated by a motor with a step-down gear-box.

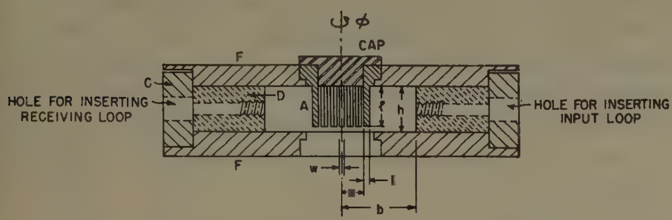


Fig. 1—Cross section of demountable resonator.

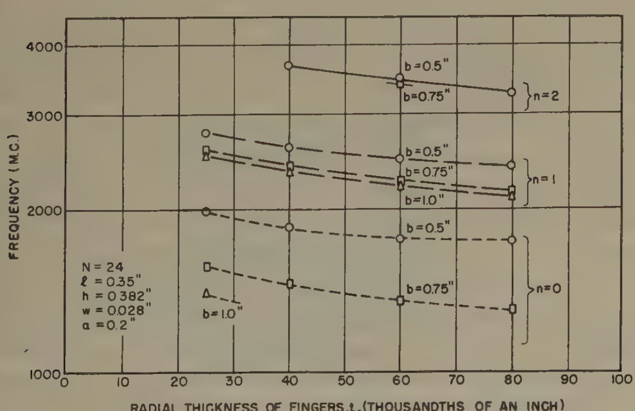


Fig. 2—Variation of frequency with capacity at the anode.

Graphs of resonance frequency of the different modes as a function of resonator parameters are given in Figs. 2 and 3. There N stands for the total number of fingers and n stands for the order of the mode. The symbols for other parameters are explained in Fig. 1. The following general conclusions can be drawn from the data:

1. The ratio by which the frequency decreases for a given increase of cavity radius is smaller for higher-order modes. Consequently, as the ratio of cavity radius to anode radius (denoted by b/a) increases, the separation of adjacent modes also increases. In a typical case, the separation between the zero- and first-order modes increases from 41 per cent to 68 per cent as b/a increases from 2.5 to 3.75. Under the same conditions the separation between first- and second-order modes increases from 41 per cent to 52 per cent.

2. Increase of radial thickness of the fingers, or decrease of separation between adjacent fingers reduces the resonance frequencies in a ratio which is nearly the same for the various orders. Thus the mode separations do not depend critically on these two parameters.

These conclusions would be of assistance in obtaining desired intervals between the modes of various orders.

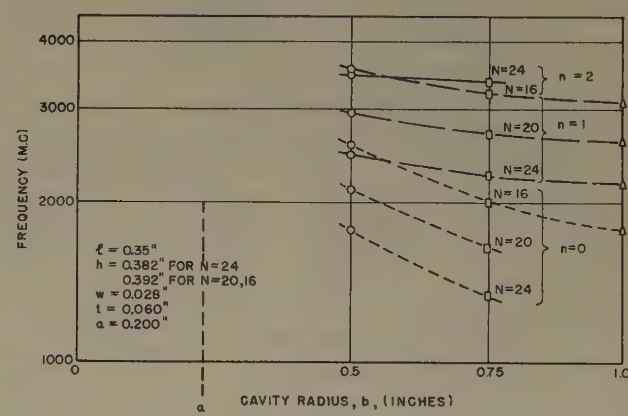


Fig. 3—Variation of frequency with cavity radius.

Modes of Interdigital Resonator with Shorting Wires at Fingers

In the early stages of this work shorting wires were used to solve the problem of degeneracy in nonzero-order modes. At that time the primary interest was in getting only a second-order mode to give steady operation. The resonator had 24 ordinary fingers, and four phase-shifting fingers located at intervals of 90 degrees. The tips of these four fingers were short-circuited to the opposite face of the cavity. It was expected that all the modes except the second-order mode with nodes of E-field at the shorting wires would become inoperable.

However, it was found that the other second-order mode and the two first-order modes were still operable. The shorting wires had greatly distorted their field patterns, and raised their frequencies. The higher second-order mode was separated from the undisturbed second-order mode by an interval of 32 per cent, and the two first-order modes were separated from the latter by intervals of 4 and 2 per cent respectively. Fig. 4 (next page) shows the field patterns of the 3 lowest modes. Locations of phase-shifting fingers are represented by P, and that of the coupling loop by L.) It is seen that the E-field of the first-order modes was nearly zero in opposite quadrants. When cold tests were performed with the

shorting wires put between the faces of the cavity at successively increasing distances behind the fingers, the frequencies of the first-order modes were found to decrease. At a certain stage, the frequency of the higher second-order mode came within the range of the test oscillator, and was found to approach that of the undisturbed second-order mode. The above experiments showed that shorting wires at fingers are not suitable for frequency control. However, they suggested the possibility of using shorting wires or radial vanes in the cavity.

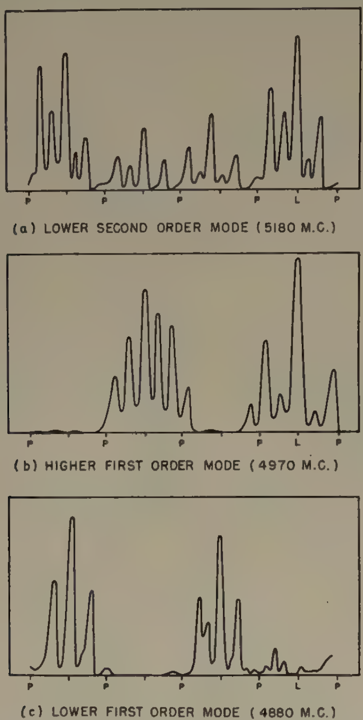


Fig. 4—Field patterns with shorting wires. (a) Lower second-order mode (5,180 mc). (b) Higher first-order mode (4,970 mc). (c) Lower first-order mode (4,880 mc).

Modes of Interdigital Resonator with Vanes in the Cavity

Further cold tests were performed using radial vanes in the cavity. A cross section of the resonator with vanes is shown in Fig. 5. Four radial slots were cut in one of the face plates, so as to lie behind the four phase shifting fingers. Vanes were inserted into these slots and clamped in place. The radial penetrations of the vanes could be varied independently. However, radially opposite vanes were always set at symmetrical locations. The resonance frequencies were determined for all the combinations of a set of values of d_a and d_b, where d_a was the radial length of one pair of vanes and d_b was that of the other pair.

Fig. 6 (page 473) shows the results in graphs of resonance frequencies versus d_a with various values of d_b as parameter. It is seen that the frequencies of the zero-order mode and of the second-order mode, which ordinarily has maxima of E-field at the position of the vanes, are increased by an increase of d_a as well as d_b. The frequency of each of the first-order modes is independent of one pair of vanes, and rises with increase in penetration of the other pair. The second-order mode having zeros of E-field at the vanes is practically unaffected by both d_a and d_b. In general, (1) insertion of vanes leaves the resonance frequency of a mode unaltered if the E-field for the undisturbed mode is zero at the positions of the vanes; (2) the resonance frequency is increased when the above condition is not satisfied; (3) the rate of increase of frequency with increase of d becomes larger as d increases.

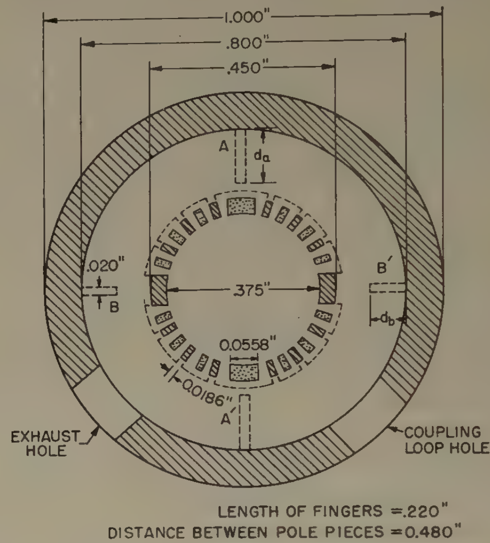


Fig. 5—Cross section of resonator.

The graphs also show how five different modes can be located at convenient intervals, with the help of two pairs of vanes in the cavity. The five modes are the zero-order mode, the two first-order modes, and the two second-order modes. By adjusting the difference between d_a and d_b the separation between the first-order modes can be adjusted. By adjusting the actual magnitudes of d_a and d_b the separation between the two second-order modes can be adjusted. In this way, intervals of the order of 9 per cent were obtained in operating tubes having a ratio of cavity radius to anode radius equal to 2:1. The intervals can be increased by increasing this ratio, as discussed in the first section.

The field patterns of the two second-order and two first-order modes obtained when vanes were used are shown in Fig. 7 (page 473). Since phase-shifting fingers were present, a regular field configuration was obtained only with the lower second-order mode, but the distortion was much less than when shorting wires were used.

It is seen that a desirable frequency spectrum can be obtained without undue distortion of the field patterns, by using vanes in the cavity. Other problems to be considered in connection with controlled operation in more than one mode relate to the Q and to the admittance presented by the fingers to the electron stream for the

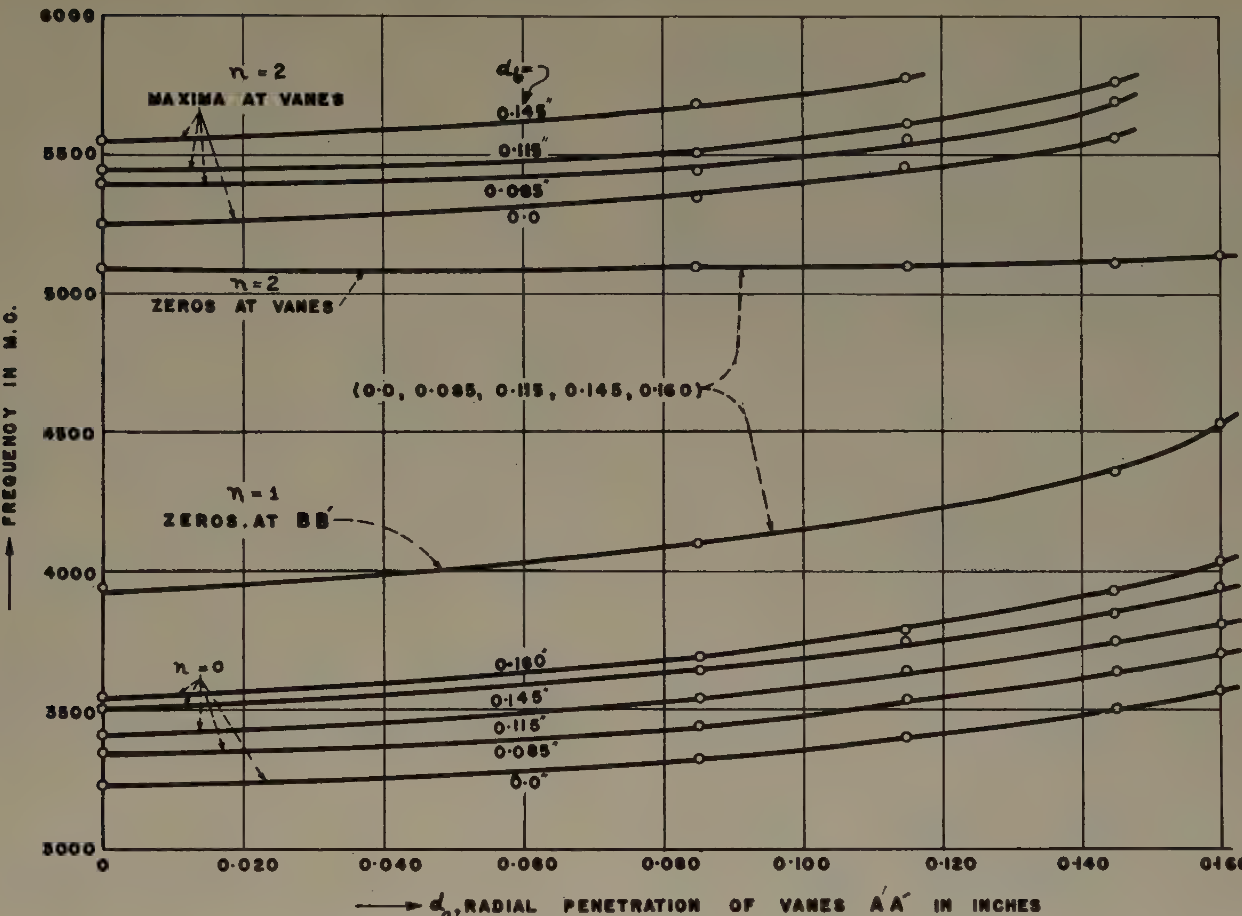


Fig. 6—Variation of resonance frequencies with penetration of vanes.

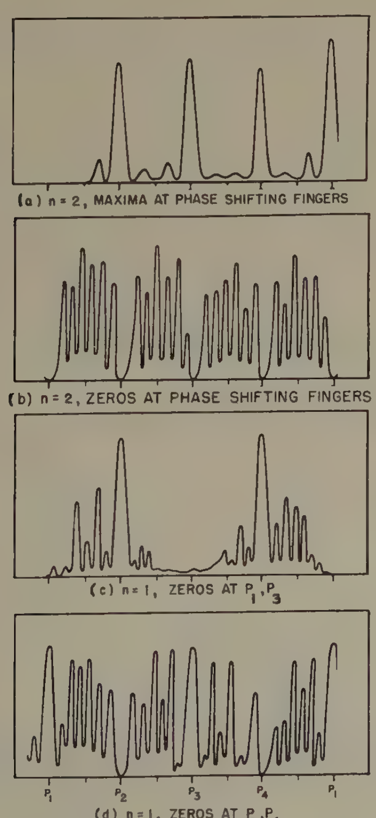


Fig. 7—Field patterns with vanes.

various modes. Some further work has been done by the author along these lines at the National Physical Laboratory of India.[13] A cavity with rectangular cross section has been used to separate the two first-order modes, keeping the surface losses small. Also the radial width of the fingers has been made to vary, so that the widest fingers are located at the axial plane parallel to the length of the cavity. In this way, further separation of the two first-order modes has been obtained, and at the same time the admittances presented to the electron stream by the two modes can be made nearly equal.

Operating Voltages of Nonzero-Order Modes

The fact that electric field in the cavity changes sign at certain locations, in the case of nonzero-order modes, results in operation being possible for each at more than one voltage. Fig. 8 (next page) shows a current vs voltage curve, at constant magnetic field, for a tube having four phase-shifting fingers. The load was matched to the transmission line at the frequency of the lower second-order mode. The duty ratio was 0.1 per cent. The curve shows that operation in the lower second-order mode and lower first-order mode was obtained in two distinct ranges of voltage in each case. The same was found to

[13] A. Singh and N. C. Vaidya, "A new method of mode control of interdigital magnetron," *Jour. Sci. Ind. Res.*, vol. 13, pp. 512–515; November, 1954.

be true for the higher first-order mode also, in other cases. Operation in more than two ranges of voltage for a given mode was observed in some cases. Such observations were made with tubes having shorting wires as well as with those having vanes. It is clear that even in the lower second-order mode more than one Fourier component could be excited, in spite of the presence of phase-shifting fingers at suitable locations. Thus it is of interest to study the Fourier components of the field configurations of different modes, with and without phase shifting fingers.

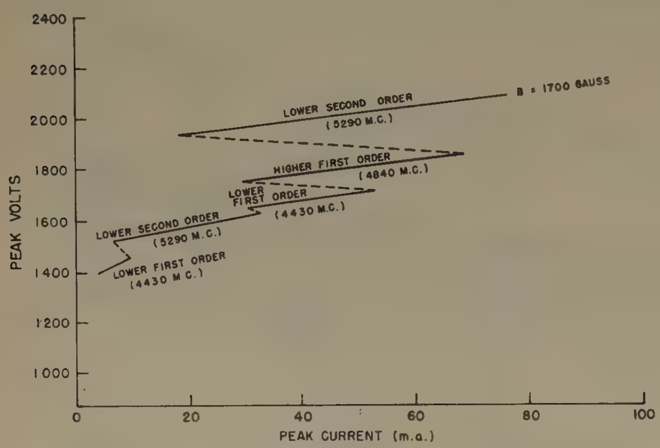


Fig. 8—Modes of operation of Tube 29.

Fourier Components of the Field Configurations

The azimuthal component $E_\phi(a, \phi)$ of the E-field at the anode in the median plane can, in the general case, be written

$$E_\phi(a, \phi) = Z(\phi) \cos n\phi P(\phi), \quad \text{or} \quad Z(\phi) \sin n\phi P(\phi),$$

where $Z(\phi)$ depends upon the total number of fingers and the ratio of gap width to finger width, and is of the nature shown in Fig. 9; n is the order of the mode; and $P(\phi)$ is a function depending upon the number and location of the phase-shifting fingers, as shown in Fig. 9. $Z(\phi)$ can be analyzed into its Fourier components as follows:

$$Z(\phi) = \frac{4}{\pi}\left\{\sin\frac{\pi}{3}\cos M\phi + \frac{1}{3}\sin\frac{3\pi}{2\rho}\cos 3M\phi + \frac{1}{5}\sin\frac{5\pi}{2\rho}\cos 5M\phi + \cdots\right\},$$

where the ratio of gap width to finger width is $1:(\rho-1)$, and M is half the total number of fingers.

When no phase-shifting fingers are present, then for higher order modes,

$$E_\phi(a, \phi) = Z(\phi) \cos n\phi$$

$$= \frac{2}{\pi}\left[\sin\frac{\pi}{2\rho}\{\cos(M+n)\phi + \cos(M-n)\phi\} + \frac{1}{3}\sin\frac{3\pi}{2\rho}\{\cos(3M+n)\phi + \cos(3M-n)\phi\} + \cdots\right].$$

Alternatively,

$$E\phi(a, \phi) = Z(\phi) \sin n\phi$$

$$= \frac{2}{\pi}\left\{\sin\frac{\pi}{2\rho}\{\sin(M+n)\phi - \sin(M-n)\phi\} + \frac{1}{3}\sin\frac{3\pi}{2\rho}\{\sin(3M+n)\phi - \sin(3M-n)\phi\} + \cdots\right\}.$$

Let γ represent the number of complete cycles around the anode, for a given Fourier component. It is seen that when no phase-shifting fingers are present, γ assumes the values $M\pm n$, $3M\pm n$ $5M\pm n$, etc.

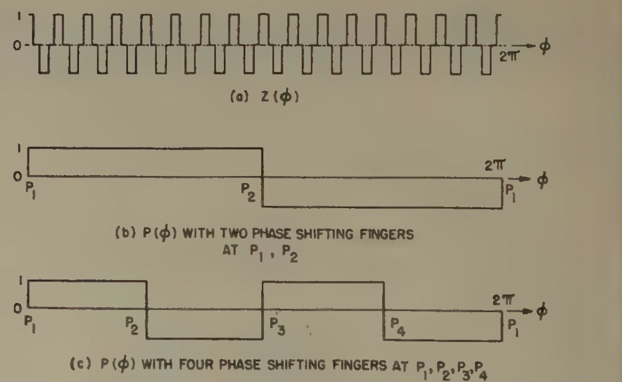


Fig. 9—Functions used for obtaining Fourier components of field configurations.

The case where four phase-shifting fingers are present is considered next. If in that case $P(\phi)$ is denoted by $P_4(\phi)$, then by Fourier analysis,

$$P_4(\phi) = \frac{4}{\pi}\sin 2\phi + \frac{4}{3\pi}\sin 6\phi + \frac{4}{5\pi}\sin 10\phi + \cdots$$

$$P_4(\phi)\sin\phi = \frac{2}{\pi}\cos\phi - \frac{2}{\pi}\cos 3\phi + \frac{2}{3\pi}\cos 5\phi - \frac{2}{3\pi}\cos 7\phi + \cdots$$

$$P_4(\phi)\cos\phi = \frac{2}{\pi}\sin\phi + \frac{2}{\pi}\sin 3\phi + \frac{2}{3\pi}\sin 5\phi$$

$$+\frac{2}{3\pi}\sin 7\phi+\cdots$$

$$P_4(\phi)\sin 2\phi=\frac{2}{\pi}-\frac{4}{3\pi}\cos 4\phi-\frac{4}{15\pi}\cos 8\phi-\cdots$$

$$P_4(\phi)\cos 2\phi=\frac{8}{3\pi}\sin 4\phi+\frac{16}{15\pi}\sin 8\phi$$
$$+\frac{24}{35\pi}\sin 12\phi+\cdots.$$

The most significant Fourier components of $E_\phi(a,\phi)$ would be obtained from the product of the first term in the expansion of $Z(\phi)$ and the function $\cos n\phi P_4(\phi)$ or $\sin n\phi P_4(\phi)$ appropriate to the given mode. The components given by the subsequent terms in the $Z(\phi)$ expansion would have their γ and excitation voltage far removed from those corresponding to the first term. Taking unity as coefficient of this first term, and expressing products as sums and differences, one obtains

$$P_4(\phi)\cos M\phi$$
$$=\frac{2}{\pi}\{\sin(M+2)\phi-\sin(M-2)\phi\}$$
$$+\frac{2}{3\pi}\{\sin(M+6)\phi-\sin(M-6)\phi\}+\cdots$$

$$P_4(\phi)\sin\phi\cos M\phi$$
$$=\frac{1}{\pi}\{\cos(M+1)\phi+\cos(M-1)\phi\}$$
$$-\frac{1}{\pi}\{\cos(M+3)\phi+\cos(M-3)\phi\}$$
$$+\frac{1}{3\pi}\{\cos(M+5)\phi+\cos(M-5)\phi\}+\cdots$$

$$P_4(\phi)\cos\phi\cos M\phi$$
$$=\frac{1}{\pi}\{\sin(M+1)\phi-\sin(M-1)\phi\}$$
$$+\frac{1}{\pi}\{\sin(M+3)\phi-\sin(M-3)\phi\}$$
$$+\frac{1}{3\pi}\{\sin(M+5)\phi-\sin(M-5)\phi\}+\cdots$$

$$P_4(\phi)\sin 2\phi\cos M\phi$$
$$=\frac{2}{\pi}\cos M\phi$$
$$-\frac{2}{3\pi}\{\cos(M+4)\phi+\cos(M-4)\phi\}$$
$$-\frac{2}{15\pi}\{\cos(M+8)\phi+\cos(M-8)\phi\}+\cdots$$

$$P_4(\phi)\cos 2\phi\cos M\phi$$
$$=\frac{4}{3\pi}\{\sin(M+4)\phi-\sin(M-4)\phi\}$$
$$+\frac{8}{15\pi}\{\sin(M+8)\phi-\sin(M-8)\phi\}+\cdots.$$

The values of γ thus obtained from the first term are $M\pm2$, $M\pm6$, etc. for the zero-order mode; $M\pm1$, $M\pm3$, $M\pm5$, etc. for the first-order modes; M, $M\pm4$, $M\pm8$, etc. for one second-order mode; and $M\pm4$, $M\pm8$, etc. for the other second-order mode.

The effect of four phase-shifting fingers has been to make the value M available for γ in one of the second-order modes. But, at the same time, in all the nonzero-order modes one pair of components has been replaced by a number, whose amplitude does not fall off so rapidly as to make their excitation improbable.

The foregoing study is helpful in explaining the observed voltages of operation. For a given mode and magnetic field, the voltage is inversely proportional to γ, to a first approximation. This approximation was considered adequate because there was uncertainty in choosing values of voltage from the data for comparison with theory, as each mode of excitation was obtained over a range of voltage. The starting point of each range was chosen for comparison with theory.

The following limitations of the above simple theory have to be recognized. The presence of any irregularities in the geometry of the resonator would introduce Fourier components not given by the above analysis. Examples of such irregularities are the coupling loop, an imperfectly aligned cathode, and irregular spacing of fingers. Yet, notice that for Fourier analysis the range of azimuth over which the function $E_\phi(a,\phi)$ was defined was 0 to 2π. However, in exciting a given field configuration, the electrons need not be in synchronism with the field over this whole range. The following shows the kind of difference between simple theory and experiment expected on the above basis. In the first-order mode, when four phase-shifting fingers are present, a value of $\gamma=M$ is not given by Fourier analysis, but an excitation voltage corresponding to $\gamma=M$ would be possible, if an electron, while giving energy to the rf field, could reach the anode without crossing the two phase-shifting fingers at the maxima of the E-field.

Comparison of Experimental Results with Theory

In these tubes M was equal to 16, as the tube had 24 ordinary fingers and four phase-shifting fingers, each one of the latter being equivalent to two ordinary ones. Data were taken on the two first-order modes, and the second-order mode whose E-field was zero at the phase-shifting fingers. The zero-order mode could not be operated since cathode decoupling chokes were not used. Operation in the other second-order mode was erratic, due to points of phase reversal around anode.

TABLE I

Tube No.	Mode	Magnetic field in Gauss	Proportions of reciprocals of voltages
22	Lower Second	1370	16.0:17.7:20.2
22	Lower Second	1920	16.0:18.3:19.9
23	Higher First	1920	16.0:17.2
23	Lower Second	1920	16.0:18.0
28	Lower Second	1700	16.0:19.9:20.8:22.0
28	Lower Second	2260	16.0:17.3:20.1:21.3
29	Lower First	1480	13.3:16.0:19.2
29	Lower First	1700	16.0:19.1:21.3
29	Lower First	2140	16.0:19.1
29	Lower First	2610	16.0:19.0
29	Lower Second	1480	16.0:20.5
29	Lower Second	1700	16.0:20.0
29	Lower Second	2140	16.0:20.5
29	Lower Second	2610	16.0:20.5

The data given in Table I above may be discussed under the following headings:

1. Within experimental error, the reciprocals of voltages for each mode are proportional to numbers in the series, 16, 16 ± 1, 16 ± 2, etc. Table I shows the actual numbers obtained in the series, 16 being taken as the reference number.

2. The presence of voltages corresponding to $\gamma=16$ and 20 in the second-order mode and to $\gamma=13$, 17, 19 and 21 in the first-order modes is in conformity with values obtained from Fourier analysis.

3. The presence of a voltage corresponding to $\gamma=16$ in the first-order modes is due to the fact that electrons can reach the anode by covering only a small range in azimuth, as already discussed. The assumption that the voltage corresponds to $\gamma=16$ was checked by using the voltage for $\gamma=16$ in the second-order mode as reference. The voltages were found to be directly proportional to the frequencies to within 1 per cent, as would be expected when γ is the same for the two cases.

4. The occasional presence of voltages corresponding to other values of γ may be ascribed to irregularities in the structure, which would modify the field and thus introduce additional Fourier components.

5. The consistent absence of a voltage corresponding to $\gamma=17$ from the lower first-order mode is understandable, since the same order of voltage can excite the $\gamma=20$ component of the lower second-order mode; and the latter appears to be more easily excited.

Before the advantage of a number of well separated modes can be exploited, the difficulty of more than one voltage of operation for the nonzero order modes will have to be removed. Phase-shifting fingers are of doubtful advantage. A different approach would be to increase the number of fingers, without using phase-shifting fingers. The separation (in percentage) of the two components will thus be reduced. Considering the fact that operation at a voltage corresponding to $\gamma=M$ is also likely in addition to those corresponding to $\gamma=M\pm n$, it appears possible that all the three voltage ranges may merge into one continuous range. This may be expected particularly for small values of n. The problem invites further work.

Conclusions

It has been shown that the degeneracy of nonzero order modes can be removed and the resonance frequencies accurately controlled, without undue distortion of the field patterns in the interaction space, by using radial vanes in the cavity. The dimensions of the fingers, the cavity, and the vanes, can be so chosen as to obtain a number of modes at desired intervals.

It was found that each nonzero-order mode normally operates at more than one voltage. The way to get around this difficulty appears to be to use a large number of ordinary fingers, without introducing any phase-reversing ones. This alternative is also to be preferred if operation in more than one mode is desired.

Acknowledgment

The guidance and encouragement received from Prof. E. L. Chaffee, Dr. D. L. Benedict and Prof. R. W. P. King are gratefully acknowledged. The work of Dr. C. Yeh and Mr. J. P. Jasionis on operating tubes using shorting wires provided the stimulus for further work on mode control. The observation that the interdigital magnetron operated at more than one voltage for a nonzero-order mode was also first made by them. The data on operating voltages of Tubes 22 and 23 were taken by Dr. Yeh.

Measurement of Minority Carrier Lifetime and Surface Effects in Junction Devices*

S. R. LEDERHANDLER†, AND L. J. GIACOLETTO‡, SENIOR MEMBER, IRE

Summary—The characteristics of junction devices are influenced to a considerable degree by the lifetime of the minority carriers. Accordingly, methods for the measurement of this quantity are of considerable importance. Methods have been described for the measurement of the lifetime of minority carriers when these carriers are produced within the volume of a semiconductor. When the minority carriers are introduced near the surface of a semiconductor the resulting effective lifetime may be determined to a large extent by the nature of the surface. For most junction devices, it is the effective lifetime that is of primary importance.

This paper describes a simple method for the measurement of effective lifetimes of injected minority carriers. The measurements may be applied to practical junction structures as, for example, an alloyed junction transistor. Measurements may be made on either completed or partially completed devices. The resulting data are potentially of value as quality controls during the fabrication of transistors and similar devices.

In many cases, the effective lifetime is a good indication of the surface conditions, and immediate evaluation of these conditions may be obtained at various stages of device processing. With selected geometries, the measurement method may be applied to determine absolute values of surface recombination velocities and should therefore be in studying surface conditions and treatments.

The measurement method is described in terms of junction devices using germanium as the semiconductor. However, the method is equally applicable to junction devices made with other semiconductor materials.

Introduction

An IMPORTANT material property which affects the performance of transistor devices is the lifetime of minority carriers in the semiconductor. This lifetime depends on the nature of the material and on the various treatments to which the material has been subjected. Electrically, it is a direct factor in many transistor parameters such as saturation current, current amplification factor, and others. It is, therefore, of considerable practical importance to be able to evaluate this factor directly on junction devices.

Earlier studies of minority carrier lifetimes have been mainly directed to evaluations as a property of the material[1] (volume lifetime) or as a property of a surface[2] (surface lifetime). As a result, the methods developed in these studies have not used the geometries of practical junction devices nor have they generally involved a *p-n* junction. This paper will describe a simple method[3] which is directly applicable to junction devices. Indeed' this method uses a *p-n* junction to inject minority carriers by means of a current pulse applied to the junction in the forward direction. The decay of the injected carriers is observed by open-circuiting the *p-n* junction and observing the junction voltage on an oscilloscope. A particular advantage for investigative work is that this measurement can be made on a single junction, thereby avoiding the more complex construction of a complete transistor. Furthermore, immediate evaluation can be made at various stages in the processing of junction units as a control in the fabrication of transistors or as a measurement in the study of process variations.

Experimental Method

The circuit of Fig. 1 shows an experimental arrangement for applying a constant current pulse in the forward direction through a *p-n* junction and, by means of a thermionic diode, open-circuiting the *p-n* junction at the termination of the current pulse. The open-circuited junction voltage is observed on an oscilloscope. Minority carriers are injected into the base region during the time the pulse is applied to the junction in the forward direction. Upon completion of the pulse, the thermionic diode effectively opens the circuit between the generator and the emitter. As a result, the junction voltage is a direct measure of what happens to the injected carriers. A typical open-circuited voltage wave form is also illustrated in Fig. 1 (voltage at *b-b'*).

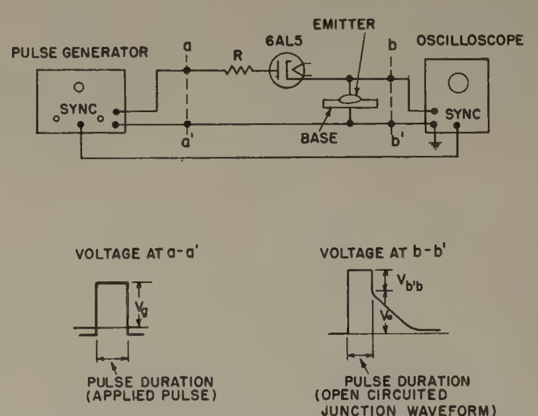


Fig. 1—Circuit illustration for applying constant current pulse to emitter-base junction and observing an open-circuited junction voltage upon termination of pulse.

It is observed that, after an initial drop due to an internal series resistance, the open-circuited junction voltage decays approximately linearly with time, and this linear decay is followed by an approximately exponen-

* Original manuscript received by the IRE, December 1, 1954; revised manuscript received, January 28, 1955.

† Formerly RCA Labs., Princeton, N. J. Now with Research Division, Raytheon Mfg. Co., Waltham, Mass.

‡ RCA Labs., Princeton, N. J.

[1] L. B. Valdes, "Measurement of minority carrier lifetime in germanium," Proc. I.R.E., vol. 40, pp. 1420–1423; November, 1952.

[2] D. Navon, R. Bray, and H. Y. Fan, "Lifetime of injected carriers in germanium," Proc. I.R.E., vol. 40, pp. 1342–1347; November, 1952.

[3] A related development has been described by B. R. Gossick, "Post-injection barrier electromotive force of *p-n* junction," *Phys. Rev.*, vol. 91, pp. 1012–1013; August 15, 1953.

tial decay. As will be shown below, this linear portion of the voltage variation lends itself very readily to computation of a minority carrier lifetime, which is here designated as an *effective lifetime* since it results from the combined effect of volume and surface lifetimes.

In Fig. 2 there is shown a flexible circuit for use in connection with a suitable pulse generator and an oscilloscope for observing either the reverse bias (to be described subsequently) or the open-circuited junction voltage. The pulse rise time and more important, the pulse decay time of the pulse generator, should be reasonably small—1/10 of the effective lifetimes to be measured should be adequate. Pulse length and repetition frequency usually used are 10 μsec and 3,000 p/sec, but the exact values employed are not important. The pulse amplitude and generator output impedance are also of no great importance. The oscilloscope response should be at least comparable to the pulse generator decay time mentioned above. It is important that the vertical amplification and horizontal trace speeds be calibrated. A differential oscilloscope connected as shown in Fig. 2 is a convenient means for measuring the pulse current flowing through the junction device. The 1.3-volt battery is inserted in series with the diode to eliminate a spurious voltage arising from the thermal velocities of the cathode-emitted electrons. A reversing switch is provided to accommodate both n-type and p-type devices with a single socket arrangement. A transparent alignment device with radial lines engraved thereon can be used for measuring effective lifetimes easily and quickly from oscilloscope displays of open-circuited junction voltages. When the vertical deflection sensitivity and horizontal sweep time are suitably adjusted, the effective lifetime is read directly by aligning one of the radial lines with the linear portion of the open-circuit junction-voltage waveform.

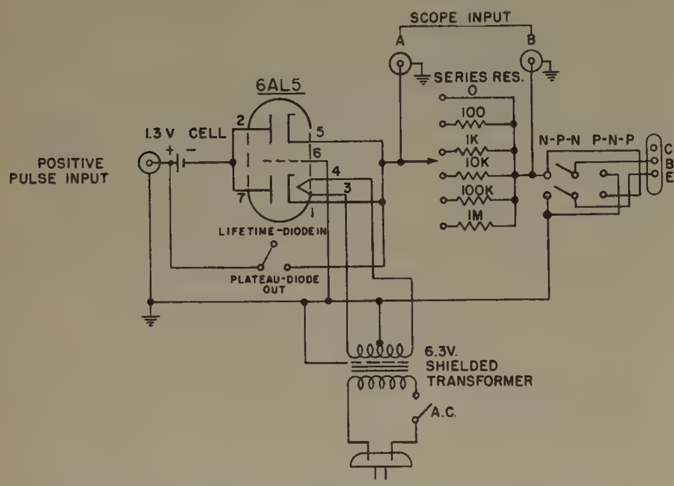


Fig. 2—Circuit used for the measurement of effective lifetime and related characteristics.

Theoretical Development

A theoretical interpretation of the observed junction voltage can be made on the basis of simple but approximate junction theory. A p-n junction in which the conductivity of the p-region is much greater than that of the n-region, as in an alloyed junction of indium on germanium, will be considered. In such a junction, the current flow across the transition region of the junction is predominantly a hole flow, and holes are injected into the n-type germanium. The results, however, will apply with equal validity to a junction in which the conductivity of the n-region is much greater than that of the p-region. In this case, electrons would be injected into the p-type region.

Let p_n be the hole density present in the n-region under themal equilibrium conditions, and Δp be the additional injected hole density in the n-region at the boundary of the junction transition region. The total hole density at the junction boundary will be

$$p = p_n + \Delta p. \tag{1}$$

From the theory of the p-n junction,[4] the hole density in the n-region at the junction boundary is given by

$$p = p_n e^{qV/kT}, \tag{2}$$

where V is the junction voltage. Combining (1) and (2) the solving for the voltage,

$$V = \frac{kT}{q} \ln\left(1 + \frac{\Delta p}{p_n}\right). \tag{3}$$

If the assumption is made that the excess carrier concentration, Δp, decays exponentially according to a single effective lifetime, τ_e, then

$$\Delta p = \Delta p_0 e^{-t/\tau_e}, \tag{4}$$

where Δp_0 is excess carrier concentration at the termination of the forward current pulse. Eq. (4) can be placed in (3). The constant $(1+\Delta p_0/p_n)$ can be readily evaluated in terms of the junction voltage, V_0, at $t=0$ (this is the junction voltage immediately before and immediately after the removal of the forward pulse—see Fig. 1), since

$$V_0 = \frac{kT}{q} \ln\left(1 + \frac{\Delta p_0}{p_n}\right). \tag{5}$$

The open-circuited junction voltage as a function of time is then

$$V = \frac{kT}{q} \ln\left[1 + (e^{qV_0/kT} - 1)e^{-t/\tau_e}\right]. \tag{6}$$

For t/τ_e very small, and if, as usual, $V_0 \gg kT/q$ (6) may be simplified to

[4] William Shockley, "Electrons and Holes in Semiconductors," D. Van Nostrand Company, Inc., New York, p. 312; 1950.

$$V \cong V_0 - \frac{kT}{q} t/\tau_e. \tag{7}$$

The initial voltage variation is linear with time. The slope of the linear variation is a measure of the effective lifetime.

$$\tau_e = -\frac{\Delta t}{\frac{q}{kT}\Delta V} = -\frac{kT}{q} \times \frac{1}{\text{Slope of Linear Decay}}. \tag{8}$$

The values of Δt and ΔV may be read directly with the use of a calibrated oscilloscope. Fig. 3 shows some typical voltage wave shapes and some typical calculations for effective lifetimes.

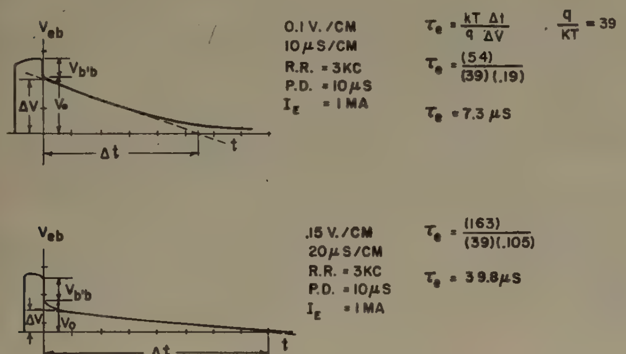


Fig. 3—Measurement of effective lifetime emitter-to-base open-circuited junction voltage.

The basic p-n junction theory applied above and based on (2) assumes that the injected minority carrier density is small compared with the majority carrier density. Accordingly, accurate measurements of τ_e should be made using small enough currents so that this assumption is valid. However, if the current is too small, a well-defined linear region is not obtained. For most of the devices that have been measured, a junction current of about 2 ma has been appropriate. When the junction current is increased so as to invalidate the assumption mentioned above, calculations similar to those above can be carried out, but the results are considerably more complex. The voltage decay for this case, as viewed on the oscilloscope, will exhibit a "hump" separating two regions of approximate linear decay. The latter decay corresponding to the region where the minority carriers are again small compared with the majority carriers can be used for measurement.

As is implied above, the preceding analysis does not possess a high degree of rigor. Only the life history of the holes has been considered, and the manner of their decay has been assumed without consideration of accompanying diffusion effects. In Appendix I this problem is examined in a more rigorous fashion. Both hole and electron carriers with independent lifetimes as well as diffusion effects are included. It is again assumed that the minority carrier density is small compared with the majority carrier density. A study of the solution indicates that as long as the portion of the junction current due to minority carriers (holes) is approximately equal to the total junction current (injection efficiency, γ, $=1$), then the resulting junction voltage decay will be that due to holes irrespective of the lifetime of the electrons. Further, it appears that the method of measuring lifetime discussed above should give results that are adequate for engineering purposes. As an additional check, the method of measuring lifetime discussed herein has been compared with another more involved method of measurement, and good agreement between the two methods of measurement has been obtained.[5]

Lifetime Measurements

Typical Measurements

Measurement of effective lifetimes for p-n-p junction transistors will give results generally ranging from 1 to 10 μsec.[6] Sample diodes made with materials having volume lifetimes of 1, 4, and 700 μsec gave effective lifetimes of 0.5, 3.4, and 39.8 μsec, respectively. Effective lifetimes as small as 0.01 μsec have been measured.

It is important to observe that the effective lifetime of the units made from material having 700 μsec volume lifetime was measured as only 39.8 μsec. On the other hand, the effective lifetime measured on units which were made from low volume lifetime material was quite close to the volume lifetime. This seems reasonable assuming effective lifetime to be a measure of the combined effects of volume recombination and surface recombination. In accordance with calculations for simple geometries,[7] effective lifetime, τ_e, volume lifetime, τ_v, and surface lifetime, τ_s, are related as

$$\frac{1}{\tau_e} = \frac{1}{\tau_v} + \frac{1}{\tau_s}. \tag{9}$$

The surface lifetime, τ_s, will be dependent upon the geometry and upon the surface recombination velocity. For a fixed geometry, the effective lifetime together with the volume lifetime (measured by conventional methods on the bulk material) can be used for determining a surface lifetime which is directly related to the surface treatment. When the volume lifetime is much larger than the measured effective lifetime (as is usually the case in practical device geometries), effective lifetime is very nearly a measure of surface lifetime and can accordingly be used as an index of surface treatment.

[5] These measurements were carried out by Dr. A. R. Moore, RCA Laboratories and utilize the decay of photoconductivity following illumination with a pulsed light source. This technique has been described by D. T. Stevenson and R. J. Keyes, "Measurement of lifetimes and diffusion constants in germanium," *Phys. Rev.*, vol. 94, p. 1416; June 1, 1954.

[6] R. R. Law, C. W. Mueller, J. I. Pankove, and L. Armstrong, "A developmental germanium p-n-p junction transistor," Proc. I.R.E., vol. 40, pp. 1352–1357; November, 1952.

[7] W. Shockley, *op. cit.*, pp. 318–325.

TABLE I

CHANGE IN EFFECTIVE LIFETIME VALUES AS A RESULT OF ETCHING

Specimen	τ_v Volume Lifetime	τ_e After Fabrication and chemical etch $s=400$ cm/sec	τ_e Dipped in etch containing $Cu(NO_3)_2$ $s=7400$ cm/sec	τ_e Electrolytic etch 2 min 2 ma $s=250$ cm/sec	τ_e Electrolytic etch 5 min 3 ma $s=250$ cm/sec	τ_e Electrolytic etch 5 min 3 ma $s=250$ cm/sec
T-6	4 μsec	3.4 μsec	1.8 μsec			
T-61	700 μsec	37 μsec	4.1 μsec	40 μsec	58 μsec	58 μsec

Effects of Etching on Effective Lifetime

To observe the effect of surface treatment on effective lifetime, two germanium alloy junctions having 0.045-inch diameter emitter dots, base wafer-thickness of 0.005 inch, and volume lifetimes that were substantially different were first chemically etched and measured and then dipped in an etch containing copper nitrate for 15 seconds. This etch was chosen because of its ability to produce a high surface recombination velocity which has been reported to be approximately 7,400 cm/sec.[8] It was noticed upon removing the junction from the etch that copper was deposited on the dot and on the germanium surface. Following the etch treatment, the effective life was measured and indicated a substantial lower lifetime than before etching. The copper was next removed by an ammonia and hydrogen-peroxide solution, and the unit was washed in distilled water. The junction was then electrolytically etched in 1 per cent sodium hydroxide for two minutes at 2 ma current. Subsequent measurement of effective lifetime indicated a decided increase from its previous value. The effective lifetime was further increased by additional electrolytic etching; subsequent etching produced no further increase in τ_e. The measured data for the sequence of etching together with reported values of surface recombination velocities produced by these etching solutions on germanium are shown in Table I.[8] The data in Table I indicate that there is a close correlation between surface recombination velocity and effective lifetimes when the volume lifetime is large. With the aid of (9), $\tau_s=39.5$, 4.12, and 63.3 μsec are obtained for the chemical etch, containing copper nitrate, and electrolytic etches, respectively. If these surface lifetimes are proportionally related to surface recombination velocities as

$$\frac{1}{\tau_s} = Ks \tag{10}$$

values of the geometrical factor, K, can be computed as 63.2, 32.8, and 63.2 cm^{-1}. If the second value is discarded, a geometrical factor of 63.2 cm^{-1} is applicable for the units described above. Data similar to that shown in Table I can be used to obtain geometrical factors for different junction devices. After the geometrical factor of the unit has been determined, measurements of effective lifetime and volume lifetime can be used for determining the surface recombination velocity of completed or partially completed units. Often only a relative comparison of surface treatments is desired. In this case, the geometrical factor need not be determined. The surface lifetime serves as an index of comparison.

Absolute Determination of the Surface Recombination Velocity

It is sometimes necessary to make a direct determination of surface recombination velocity. Thus, the efficacy of the etching solution may be in question, or a new solution may need calibration.

The absolute calibration can be made by using a junction geometry amenable to analysis as carried out by Shockley.[9] Thus, for the geometry as shown in Fig. 4,

$$s = \frac{1}{\tau_s\left[\dfrac{1}{B} - \dfrac{1}{C}\right]}. \tag{11}$$

The dimensions of the sample are not critical. It has been convenient to use wafers whose dimensions are $2A=0.215$ inch, $2C=0.125$ inch and $2B=0.005$ inch.

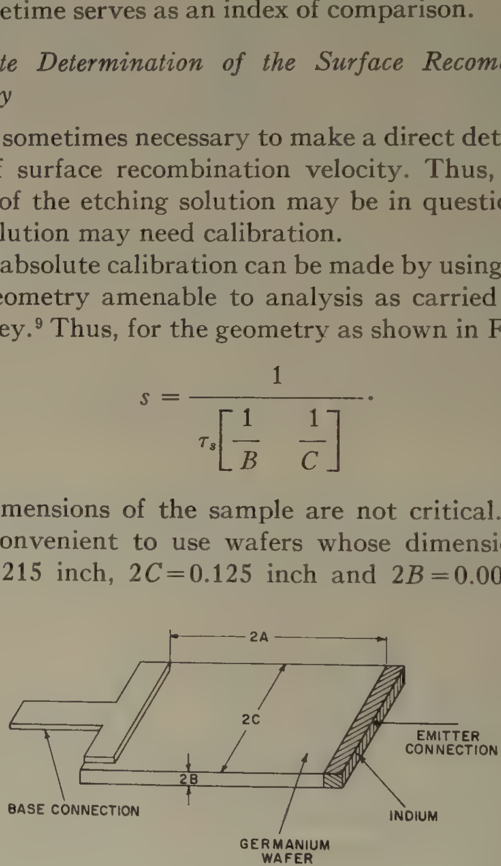


Fig. 4—Device for direct measurement of surface recombination velocity.

The $2A$ dimension should be chosen several times larger than the volume diffusion length. The $2B$ dimension should preferably be chosen so as to be the dominant term in (11). In this case then, (11) is valid as long as $s(2B/D)\leq 1$ (D is the diffusion constant for the minority carriers under consideration).

As a typical example of the application of this method of direct determination, several specimens were made with germanium whose volume lifetime was $\tau_v=700$

[8] A. R. Moore and J. I. Pankove, "The effect of junction shape and surface recombination on transistor current gain," PROC. I.R.E., vol. 42, pp. 907–913; June, 1954.

[9] W. Shockley, "The theory of p-n junctions in semiconductors and p-n junction transistors," *Bell Sys. Tech. Jour.*, vol. 28, pp. 435–489; July, 1949. See also W. Shockley, *op. cit.*, pp. 318–325.

μsec. The effective lifetime for these specimens averaged 36.5 μsec. Accordingly, using (9), $\tau_s = 38.5$ μsec is computed. Finally, with the aid of (11), $s = 320$ cm/sec is computed. The surface treatment in question was an electrolytic etch so that this value of s is in good agreement with $s = 250$ cm/sec that has been previously used (see Table I).

Measurement of Base-Lead Resistance

In an alloyed junction device the base-lead resistance, $r_{bb'}$ is the majority carrier (ohmic) resistance of the semiconductor between the metallic contact to the semiconductor and the region near the actual *p-n* junction. It is an important factor in the performance of many junction devices.[10]

The method of measurement to be described below measures a diode base-lead resistance which is generally different from that of the corresponding device operating as a transistor. This difference is due to the dissimilar current distribution within the body of the semiconductor for diode and transistor operation.

The initial drop in the open-circuited junction voltage upon termination of the pulse can be used for the measurement of the resistance. The voltage, $V_{b'b}$, corresponding to the drop across $r_{bb'}$ is shown in Figs. 1 and 3. If the positive amplitude of the generator pulse, V_g, is measured, then $r_{bb'} = V_{b'b}\,R/V_g$, where R is the current limiting resistance in series with the pulse generator. This assumes that the voltage drop across the 6AL5 tube, the voltage across the junction, and the voltage of the series battery are negligible in comparison with the voltage drop across the current limiting resistor. If this assumption is not valid, the junction current just before the pulse is removed can be determined by measuring the appropriate voltage across R with the aid of the differential input to the oscilloscope (see circuit of Fig. 2).

Observations of Reverse Bias Waveform

During the course of this work experimental observations were made of the junction recovery voltage under conditions of applied reverse bias. In this case, a reverse bias is applied to the junction immediately after the termination of the forward pulse. The junction waveform under these conditions is observed on an oscilloscope. This type of switched junction operation has been investigated.[11–14] Since the interpretation of the observed waveform is somewhat more complex than that of the open-circuited case discussed above, this observation was not developed into a system for the determination of minority carrier lifetimes. However, qualitative observations made under these conditions may be quite valuable, and in some cases this method of operation is a more sensitive indication of whether or not minority carriers are being injected. A switch is included in the circuit of Fig. 2 to enable this observation to be made. This switch shorts out the 6AL5 diode and bias battery and is labeled "plateau-diode out." The reverse bias is supplied by a blocking condenser in the output of the generator. This condenser becomes charged during the forward pulse. After the forward pulse is terminated, the charged blocking condenser applies a reverse bias to the *p-n* junction.

Observations of the junction waveform under the conditions of a reverse bias following a forward pulse (see Fig. 5) show first an immediate drop in voltage after the termination of the pulse due to the base-lead resistance.

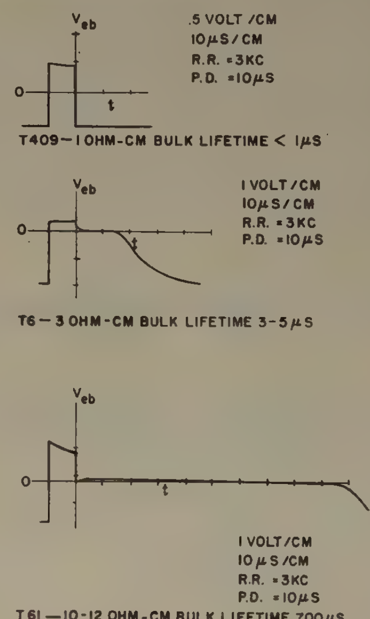


Fig. 5—Variation in plateau length of emitter-base voltage for different base wafer lifetimes.

This is similar to that discussed above in the case of the open-circuited junction voltage. This immediate drop in voltage is generally followed by an extended period of approximately zero voltage after which the reverse voltage across the junction gradually increases in magnitude as the injected carriers recombine and permit the junction to be biased in the reverse direction. The existence of the zero-voltage plateau indicates that minority carrier injection has taken place. These observations can be utilized in a qualitative manner to check for minority carrier injection and as a qualitative observation of the effective lifetime. These effects are illustrated by the experimental observations shown in Fig. 5. This figure shows the experimental waveforms under the reverse bias conditions observed on junction diodes made from

[10] L. J. Giacoletto, "Study of *p-n-p* alloy junction transistor from dc through medium frequencies," *RCA Rev.*, vol. 15, pp. 506–562; December, 1954.

[11] E. M. Pell, "Recombination rate in germanium by observation of pulsed reversed characteristics," *Phys. Rev.*, vol. 90, pp. 278–279; April 15, 1953.

[12] R. G. Shulman and M. E. McMahon, "Recovery currents in germanium *p-n* junction diodes," *Jour. Appl. Phys.*, vol. 24, pp. 1267–1272; October, 1953.

[13] R. H. Kingston, "Switching time in junction diodes and junction transistors," Proc. I.R.E., vol. 42, pp. 829–834; May, 1954.

[14] B. Lax and S. F. Neustadter, "Transient response of a *p-n* junction," *Jour. Appl. Phys.*, vol. 25, pp. 1148–1154; September, 1954.

germanium having different volume lifetimes. It is seen that, for the unit made from germanium having a volume lifetime of less than 1 microsecond, there is essentially no plateau region. An appreciable plateau region is observed in the second case for the unit having a volume lifetime between 3 and 5 microseconds. Finally, a rather extended plateau is observed in the third case for a unit made from material having a volume lifetime of 700 microseconds.

Appendix I: Open-Circuited Junction Voltage

This appendix contains the solution for the open-circuited junction voltage following operation in the forward direction when both holes and electrons with independent lifetimes are considered, and when the movement of these carriers is governed by the one-dimensional continuity equation. The material in this appendix is the work of Dr. D. O. North, RCA Laboratories, Princeton, New Jersey.

The p-n junction is operated in a forward direction until a steady-state condition is reached, and at time $t=0$, the forward bias is removed and the open-circuited junction voltage determined as a function of time. The solution for the open-circuited junction voltage when displacement currents are neglected and when the minority carrier density is small compared with the majority carrier density is

$$\begin{aligned}\frac{e^{\Lambda V(t)}-1}{e^{\Lambda V_0}-1} &= \frac{J_p}{J_p-J_n}\left[1-\operatorname{erf}\sqrt{\frac{t}{\tau_p}}\right] \\ &\quad -\frac{J_n}{J_p-J_n}\left[1-\operatorname{erf}\sqrt{\frac{t}{\tau_n}}\right] \\ &\quad +\frac{\sqrt{J_nJ_p}}{J_p-J_n}\sqrt{A}e^{-Bt}\left[\operatorname{erf}\sqrt{\frac{J_n}{J_p}A\frac{t}{\tau_p}}\right. \\ &\quad \left. -\operatorname{erf}\sqrt{\frac{J_p}{J_n}A\frac{t}{\tau_n}}\right], \qquad (12)\end{aligned}$$

where

$$A=\frac{J_pJ_n(\tau_p-\tau_n)}{J_p^2\tau_p-J_n^2\tau_n}, \qquad (13)$$

$$B=\frac{J_p^2-J_n^2}{J_p^2\tau_p-J_n^2\tau_n}, \qquad (14)$$

and the various quantities have the following meaning:

$\Lambda=\dfrac{q}{kt}$ of suitable sign so that ΛV_0 is a positive quantity,

$V(t)$ = open-circuited junction voltage following $t=0$,

V_0 = forward junction voltage at $t=0$.

τ_n, τ_p = electron and hole lifetimes in p-type and n-type semiconductors, respectively.

$J_n=n_p\sqrt{\dfrac{D_p}{\tau_n}}$ = thermally generated electron current density in p-type semiconductor.

$J_p=p_n\sqrt{\dfrac{D^n}{\tau_p}}$ = thermally generated hole current density in n-type semiconductor.

n_p, p_n = electron and hole density present in p-type and n-type semiconductors respectively under equilibrium condition.

D_n, D_p = electron and hole diffusion constant in p and n semiconductors respectively.

$$\operatorname{erf} y=\frac{2}{\sqrt{\pi}}\int_0^y e^{-x^2}dx.$$

The solution given above is applicable to the general case where the n-type and p-type semiconductors have arbitrary characteristics. Certain special cases can now be considered.

1. If neither $\tau_n\to 0$ or $\tau_p\to 0$ and n_p and p_n remain finite, then respectively $J_n\to\infty$ or $J_p\to\infty$ and $V(t)=0$. This is the case when the minority carrier lifetime in either semiconductor approaches zero.

2. If $J_n\to 0$ by $n_p=0$, then

$$\frac{e^{\Lambda V(t)}-1}{e^{\Lambda V_0}-1}=1-\operatorname{erf}\sqrt{\frac{t}{\tau_p}}.$$

Since $n_pp_p=n_i^2$ = a constant, $n_p\to 0$ is the same as $p_p\to\infty$. This is the case of the conductivity of the p-type semiconductor being infinitely large. In this event the minority carrier lifetime, τ_n, can be arbitrarily small provided only that $J_n\to 0$. The same limit solution is obtained if $J_n\to 0$ by $\tau_n\to\infty$. Due to the symmetry of (12), the solution for $J_p\to 0$ is obtained by interchanging τ_n for τ_p.

3. If $\tau_p=\tau_n=\tau$, then

$$\frac{e^{\Lambda V(t)}-1}{e^{\Lambda V_0}-1}=1-\operatorname{erf}\sqrt{\frac{t}{\tau}},$$

irrespective of the values of J_n and J_p.

4. If $J_n=J_p$, then

$$\begin{aligned}\frac{e^{\Lambda V(t)}-1}{e^{\Lambda V_0}-1} &= 1-\frac{1}{2}\left[\operatorname{erf}\sqrt{\frac{t}{\tau_p}}+\operatorname{erf}\sqrt{\frac{t}{\tau_n}}\right] \\ &\quad -\frac{1}{2}\left[\operatorname{erf}\sqrt{\frac{t}{\tau_p}}-\operatorname{erf}\sqrt{\frac{t}{\tau_n}}\right] \\ &\quad \cdot\left[\frac{\tau_p+\tau_n}{\tau_p-\tau_n}+\frac{4t}{\tau_p-\tau_n}\right] \\ &\quad +\frac{2}{\sqrt{\pi}(\tau_p-\tau_n)}\left[\tau_n\sqrt{\frac{t}{\tau_n}}e^{-t/\tau_n}\right. \\ &\quad \left.-\tau_p\sqrt{\frac{t}{\tau_p}}e^{-t/\tau_p}\right]\end{aligned}$$

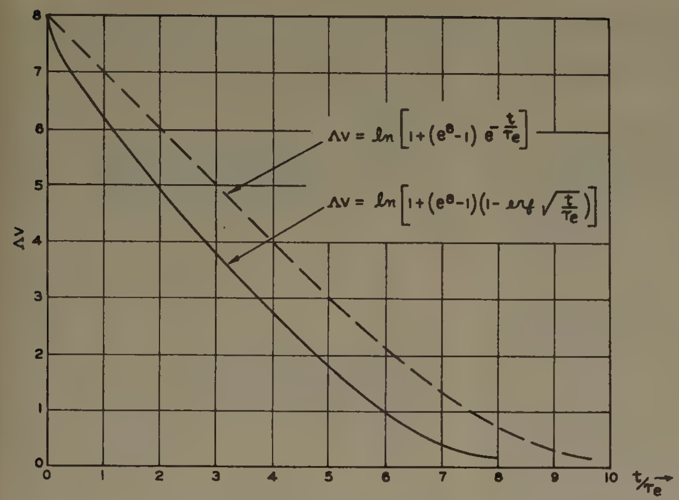


Fig. 6—Comparison of voltage decay for exponential and error function time dependency.

Case 2 is the solution applicable to the operation considered herein. This solution differs from the solution given in (6) which states that

$$\frac{e^{\Delta V(t)}-1}{e^{\Delta V_0}-1}=e^{-t/\tau_p}.$$

When the injected minority carrier density is small, the voltage decay does have a form similar to that given by the error function solution as shown in Fig. 6 for an arbitrary case of $\Lambda V_0=8$. For a somewhat larger minority carrier injection level, the voltage decay has more nearly the form of that given by the exponential solution also shown in Fig. 6 for comparison. At still larger minority carrier injection the voltage decay exhibits a "hump" as described in the text.

Correspondence

Understanding the Gyrator*

The gyrator, postulated by Tellegen[1] as a new nonreciprocal network element, is attracting the attention of network theorists nowadays. Shekel[2] has shown that a four-pole network with nonreciprocal admittance matrix $\|Y_{ij}\|$ can be separated into the parallel combination of a reciprocal network and a gyrator (Fig. 1) of gyrating admittance $\gamma=(Y_{12}-Y_{21})/2$, i.e.

$$\|Y_{ij}\|=\left\|\begin{matrix}Y_{11} & Y_{12}-\gamma\\ Y_{21}+\gamma & Y_{22}\end{matrix}\right\|+\left\|\begin{matrix}0 & \gamma\\ -\gamma & 0\end{matrix}\right\|.$$

Carlin[3] has found the necessary and sufficient conditions for the synthesis of nonreciprocal networks by means of reciprocal networks and real gyrators.

The gyrator's physical significance can be seen from the equivalent circuit of Fig. 2 with admittance matrix $\|Y_{ij}\|$; for an arbitrary value of the admittance Y_2 there follows:

$$Y_1=Y_{11}-Y_2,\qquad Y_3=Y_{22}-Y_2$$
$$I'=(Y_{12}+Y_2)V_2,\quad I''=(Y_{21}+Y_2)V_1.$$

* Received by the IRE, January 6, 1955.

[1] B. D. H. Tellegen, "The Gyrator, a New Electric Network Element," Philips Res. Rep. 3, pp. 81–101; 1948.

[2] J. Shekel, "The gyrator as a 3-terminal element," Proc. I.R.E., vol. 42, pp. 1014–1016; August, 1953.

[3] H. J. Carlin, "Theory and Application of Gyrator Networks," Polytechnic Inst. of Bklyn., Res. Rep. 289; March, 1954.

Considering separately the system of two current generators it is seen that its total input power is Re $(Y_{12}+Y_2+Y_{21}^*+Y_2^*)V_1^*V_2$.

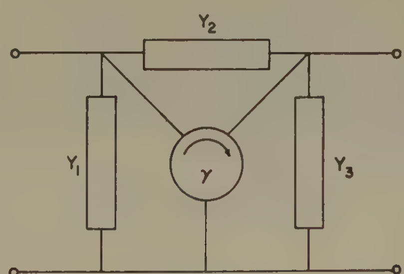


Fig. 1—Separation of a gyrator from a nonreciprocal network.

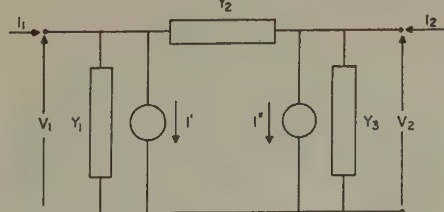


Fig. 2—π-equivalent circuit of a nonreciprocal network.

If in particular $Y_2=-(Y_{12}+Y_{21})/2$, this power is zero and the system (I', I'') reduces to the gyrator.

Similarly, starting from the network's impedance matrix $\|Z_{ij}\|$ and assuming an equivalent circuit of the type of Fig. 3, there follows for an arbitrary value of the impedance Z_2

$$Z_1=Z_{11}-Z_2\qquad Z_3=Z_{22}-Z_2$$
$$V'=(Z_{12}-Z_2)I_2\qquad V''=(Z_{21}-Z_2)I_1.$$

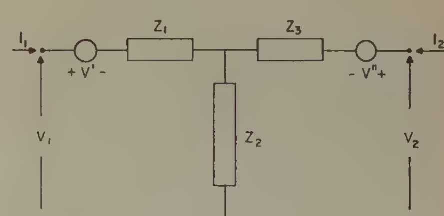


Fig. 3—T-equivalent circuit of a nonreciprocal network.

In particular, if $Z_2=(Z_{12}+Z_{21})/2$, the system of two voltage generators reduces to a gyrator of gyrating impedance $\zeta=(Z_{21}-Z_{12})/2$.

These considerations suggest methods of simple realization of gyrators by means of current or voltage generators.

L. M. Vallese
Elec. Engng. Dept.
Polytechnic Inst. of Bklyn.
Brooklyn 1, N.Y.

Effect of Heisenberg's Principle on Channel Capacity*

The limitations imposed by thermodynamics on the amount of energy necessary to transmit one bit of information, has been discussed by Felker and Pierce.[1] A minimum of $kT \log_e 2$ ergs per bit was obtained. k is Boltzmann's constant, and T is absolute temperature.

Professor Fano has suggested that Heisenberg's principle may affect channel capacity.

The following analysis shows that the energy necessary to transmit one bit is not appreciably increased by quantum mechanical considerations, providing that

$$w \ll \frac{2}{3\pi} \frac{kT}{h}.$$

w is the channel bandwidth in cycles per second and h is Planck's constant.

Consider a simple channel of bandwidth w, with a signal power per cycle of s/w ergs, and a noise power per cycle of N/w ergs. In order to optimize efficiency, we shall assume $N>>s$.[1]

A single measurement of the signal by the receiver will, according to quantum mechanics, involve some uncertainty in its energy. Let this uncertainty in energy be denoted by ϵ. It will contribute the equivalent of less than 2ϵ ergs of additional noise power per cycle.

Associated with this energy uncertainty is an uncertainty of time of measurement, which we will call τ. Heisenberg's principle states that

$$\tau = \frac{h}{\epsilon}$$

is about the most accurate in time-of-measurement we can obtain.

To find the power of the noise equivalent to the time-of-measurement uncertainty, consider that one is observing an equivalent of signal-plus-noise of flat spectrum

$$G(f) = \frac{s}{w} + \frac{N}{w} + 2\epsilon \text{ ergs},$$

extending from $f=0$ to $f=w$.

Measuring the signal at time $t-\tau$, and using this measurement as an estimate of the value of the signal at time t, will almost always result in some error. The size of this error is the same as the amplitude of the difference between the original signal and the output of a hypothetical delay circuit of delay time τ, into which the signal could be fed.

The delay circuit is of frequency response

$$e^{2\pi i\tau f}.$$

The error signal can be obtained from the original signal, by subjecting it to a filter of frequency response

$$1 - e^{2\pi i\tau f}.$$

The spectrum of the error will be

$$\left(\frac{s}{w} + \frac{N}{w} + 2\epsilon\right) | 1 - e^{2\pi i\tau f} |^2.$$

To find the error power per cycle, we integrate this spectrum over all frequencies at which the signal exists, and divide by w, obtaining

$$\frac{1}{w}\int_0^w | 1 - e^{2\pi i\tau f} |^2 \left(\frac{s}{w} + \frac{N}{w} + 2\epsilon\right) df$$

additional ergs of "noise" power per cycle.

Although the error in time of measurement will not always be τ, but will have a probability distribution of zero mean and width τ, a more exact treatment results only in an unimportant scale factor of the order of unity.

We may approximate this integral rather well by

$$\frac{4\pi^2}{3} N\tau^2,$$

if

$$s \ll N, \qquad 2\pi w\tau \ll 1$$

and

$$2\epsilon \ll \frac{N}{w}.$$

The total additional noise contribution due to both energy and time uncertainties is

$$\frac{4\pi^2}{3} Nw\tau^2 + 2\epsilon = \frac{4\pi^2}{3} Nw \frac{h^2}{\epsilon^2} + \epsilon.$$

Since we may make ϵ arbitrary, let us choose it so that this total additional noise is minimized. We obtain

$$\epsilon = \left(\frac{4\pi^2}{3} Nwh^2\right)^{1/3} \text{ ergs}.$$

The total equivalent increase in noise power then becomes

$$3\left(\frac{4}{3}\pi^2 Nwh^2\right)^{1/3} \text{ ergs}.$$

If this noise is to contribute negligibly to the channel equivocation, it must be much less than N/w, the ordinary thermal noise power per cycle, that is

$$3\left(\frac{4}{3}\pi^2 Nwh^2\right)^{1/3} \ll \frac{N}{w}$$

or

$$6\pi wh \ll \frac{N}{w}.$$

Since $N/w = 4kT$[1], we obtain

$$w \ll \frac{2}{3\pi} \frac{kT}{h}.$$

From purely dimensional considerations, it can also be shown that additional channel equivocation approaches zero, as wh/kT approaches zero, but no clear indication could be obtained as to the relative rates of approach.

Using $T=300$ degrees absolute, we find $w << 1.6 \times 10^{13}$ cycles per second at room temperature.

This limitation on bandwidth is not serious from a practical standpoint, but even if one did want to transmit information faster than this, it would be possible to use several independent channels in parallel, keeping the bandwidth of each below the limit, and still obtain an over-all channel capacity in excess of that suggested by the formula.

From the foregoing, it appears that Heisenberg's principle imposes no additional efficiency limitations on information channels.

R. J. Solomonoff
Technical Research Group
56 West 45 Street
New York, N. Y.

* Received by the IRE, October 4, 1954; revised manuscript received, November 26, 1954.

[1] J. H. Felker, "A link between information and energy," Proc. I.R.E., vol. 40, pp. 728–729; June, 1952.

On Entropy Equivalence in the Time- and Frequency-Domains*

Shannon[1,2] has found two different expressions for the entropy of a discrete, stationary, gaussian time series, by analysis in the time- and frequency-domains, respectively. It is interesting to note that by equating these two results a relationship is obtained which is of use in evaluating certain high-order determinants. This relation was first found by Szegö,[3] and has recently been derived independently by Whittle[4,5] using a different procedure. Thus we have the pleasing example of a rather obscure identity which can now be explained heuristically by an information-theoretic argument. Further, a result of Kolmogoroff[6] and Wiener[7] on the extrapolation of a discrete stationary time series can be seen to be a natural consequence of entropy considerations.

Using Shannon's expression for the entropy of an n-dimensional gaussian distribution, we have for the entropy per term, or per degree of freedom, H, of the discrete time series $\cdots, x_{-1}, x_0, x_1, \cdots,$

$$H = \lim_{n\to\infty} \frac{1}{n} \log \left[(2\pi e)^{n/2} | a_{ij}^{(n)} |^{1/2}\right], \tag{1}$$

where $|a_{ij}^{(n)}|$ is the determinant whose elements are a_{ij}:

$$a_{ij} = \overline{x_i x_j} = \phi(| i - j |);\ i, j = 1, \cdots, n. \tag{2}$$

Elias[8] gives an expression similar to (1):

$$H = \lim_{n\to\infty} \tfrac{1}{2} \log \left[(2\pi e) | a_{ij}^{(n)} | / | a_{ij}^{(n-1)} | \right]. \tag{3}$$

Now let

$$F(f) = \begin{cases} \displaystyle\sum_{k=-\infty}^{+\infty} \phi(k)\epsilon_k \cos 2\pi fk;\ 0 \leq f \leq 1, \\ \qquad\qquad \epsilon_k = \begin{cases} 1;\ k = 0 \\ 2;\ k \neq 0 \end{cases} \\ 0;\ \text{elsewhere.} \end{cases} \tag{4}$$

* Received by the IRE, December 27, 1954. The research in this paper was supported jointly by the Army, Navy and Air Force under contract with Mass. Inst. of Tech.

[1] C. E. Shannon, "A mathematical theory of communication," *Bell Sys. Tech. Jour.*, vol. 27, pp. 379 and 623; October, 1948.

[2] *Ibid.*, section 22.

[3] G. Szegö, "Beiträge zur Theorie der Toeplitzchen Formeln," *Math. Zeit.*, vol. 6, p. 167; 1920, and vol. 9, p. 167; 1921.

[4] P. Whittle, "Hypothesis Testing in Time Series Analysis," Almquist & Wiksells AB, Uppsala, Sweden; 1951.

[5] P. Whittle, "Some results in time series analysis," *Skandinavisk Aktuarietidskrift*, vol. 1, p. 48; 1952.

[6] A. H. Kolomogoroff, "Sur l'interpolation et extrapolation des suites stationnaires," *Compt. Rend.* (Paris), vol. 208, p. 2043; 1939.
See also *Bull. Acad. Sci. (URSS)*, vol. 5, p. 3; 1941.

[7] N. Wiener, "The Extrapolation, Interpolation and Smoothing of Stationary Time Series with Engineering Applications," Technology Press; 1949.

Then

$$\phi(k) = \int_0^1 F(f) \cos 2\pi f k \, df. \qquad (5)$$

Applying Shannon's expression[2] for the entropy per degree of freedom of a gaussian process with limited spectrum, we find

$$H = \frac{1}{2} \int_0^1 \log [2\pi e F(f)] df. \qquad (6)$$

Equating (1) and (6),

$$\lim_{n \to \infty} \left| a_{ij}^{(n)} \right| = \exp \left\{ n \int_0^1 \log F(f) \, df \right\}, \quad (7)$$

a result obtained by Szegö[3] and Whittle.[4,5] They have also obtained the result of equating (3) and (6),

$$\lim_{n \to \infty} \left[\left| a_{ij}^{(n)} \right| / \left| a_{ij}^{(n-1)} \right| \right]$$

$$= \exp \left\{ \int_0^1 \log F(f) \, df \right\}, \qquad (8)$$

a limit postulated by Polya in 1915.

Finally, using a suggestion of Elias,[8] we may employ the Kolmogoroff-Wiener[6,7] prediction theory to determine the entropy of a time series term when all preceding terms are known. This entropy, for a gaussian process, is given by (3), but is also given by

$$H = \tfrac{1}{2} \log 2\pi e \sigma^2, \qquad (9)$$

where σ^2 is the variance of the irreducible error of the Kolmogoroff-Wiener procedure. This variance is found by Kolmogoroff[6] and Wiener[7] to be

$$\sigma^2 = \exp \left\{ \int_0^1 \log F(f) df \right\}. \qquad (10)$$

Substituting (10) in (9), we obtain (6). Thus expression (10) may now be understood intuitively. Further, we have a simple demonstration, on information-theoretic grounds, of the well-known result that linear prediction is optimal for a gaussian time series.

Robert Price
Lincoln Laboratory
Mass. Inst. of Tech.
Cambridge, Mass.

[8] P. Elias, "A note on autocorrelation and entropy," Proc. I.R.E., vol. 39, p. 839; July, 1951.

Beam-Hugging Plates for Unlimited Cathode Ray Deflection*

The need to present rapid single events with adequate brightness on a cathode-ray oscilloscope has driven tube makers to adopt signal deflecting plates which limit the picture height to a 2-inch on a 5-inch screen. Even such close-spaced plates require about 100 volts for a 2-inch deflection, and wideband amplifiers for much larger undistorted signal output become quite unwieldy.

It is widely believed that increased deflection sensitivity by means of long and close-spaced plates must inevitably be paid for by limiting maximum deflection. But this is not the case if lateral predeflection and twisted beam-hugging plates are used.

* Received by the IRE, December 22, 1954.

How to design such a system can be learned from Fig. 1, showing after the second anode

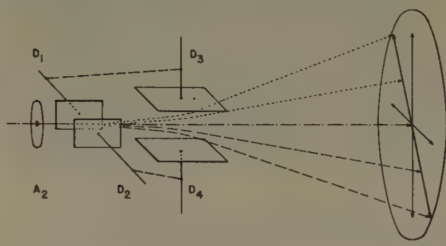


Fig. 1—All possible beam trajectories after subsidiary deflection.

A_2 two crossed pairs D_1, D_2 and D_3, D_4 of parallel plates. Omitting sweep deflection for the moment, and with the signal applied to both pairs connected together, the diagonal deflection is, of course, linearly proportional to signal voltage. The interesting point of the picture is that all possible paths—of which five are shown—of the electron beam form one twisted sheet, nowhere thicker than the beam. Therefore one may proceed in an imagined experiment in the following manner:

1. Leave the subsidiary plates D_1, D_2 unchanged (D_s).
2. Keep the main deflecting plates D_3, D_4 parallel (D_m).
3. Move D_3 and D_4 closer together, but stop wherever a surface point touches the beam; while
4. Simultaneously reducing the signal voltage applied to D_3 and D_4 in the same proportion as they are closer spaced.

With this procedure the deflecting field strength and all paths of the beam remain unchanged. At the end of the experiment both plates D_3, D_4 will just touch the sheet of possible trajectories on either surface and be twisted like it, parallel to it and to each other. But their close spacing requires much less signal voltage, although no limit is imposed on maximum angle of deflection.

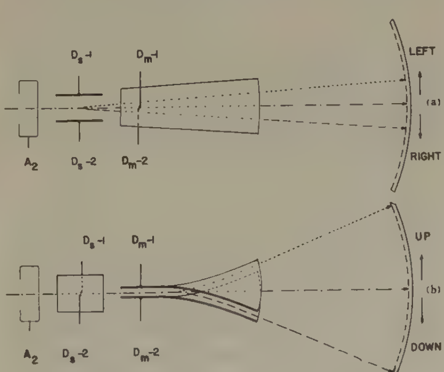


Fig. 2—Top and side view of beam-hugging deflecting plate system.

Fig. 2 shows top and side view of the so developed system D_1, D_2 combined from D_s and D_m. It is now clear that the subsidiary predeflecting plates D_s were introduced to spread the beam trajectories through the main deflecting plates. Beyond this, their contribution to the total signal deflection is of no importance. The vector diagram Fig. 3(a) shows how the total "vertical" deflection D_V is composed of D_s and D_m. A third pair of plates would provide scanning "horizontal" deflection D_H at right angle to D_V. Actually, the deflection due to the twisted main plates is more accurately represented by the—otherwise similar—diagram Fig. 3(b). The resultant deflecting angle of D_V

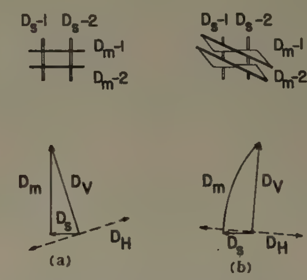


Fig. 3—End-on views of deflecting plates and resulting deflections.

depends on the relative effectiveness of the two pairs D_s and D_m but, like the shape of the plates, it is permanent for a given design. Fig. 4 shows that only one pair of signal terminals is brought out and that the location of the new sweep deflection plates D_3, D_4 is as usual.

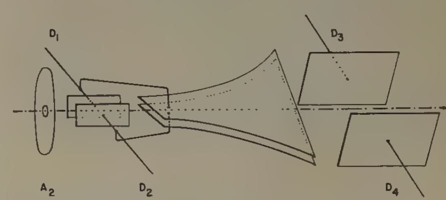


Fig. 4—Complete deflecting plate system.

The surfaces of such close-spaced plates must be accurate and smooth, or inhomogenous fields will de-focus the beam. Defocusing by image charges due to the proximity of the plates need not be feared. A recent study[1] indicates instead that space charge depression due to such plates should rather aid the focus.

A model of a 5-inch tube, 17-inches long, has been tested. The main plates were spaced approx. 0.1-inch for a length of 2.5-inches. They had less than 5 $\mu\mu f$ capacity and a sensitivity of about 6v per inch per kv acceleration without limiting full screen deflection. Transit time in such plates should reduce, at 2 kv, the sensitivity by about 4 per cent at 100 mc.

H. E. Kallmann
New York, N. Y.

[1] J. S. Hickey, Jr. and T. G. Mihran, "The spreading of an electron beam," Proc. I.R.E., vol. 40, p. 994; August, 1952.

Single-Sideband Transmission without Transient Distortion*

It has long been recognized that each sideband of an amplitude-modulated carrier contributes two components to the detector output signal, an undistorted in-phase com-

* Received by the IRE, December 22, 1954.

ponent and a 90-degree phase-displaced distortion. In double-sideband reception the former contributions add, the latter, being of opposite phase, cancel each other. If only one sideband is transmitted, failure of this cancellation shows up as a distorted transient response.[1] The vestige of the suppressed sideband in vestigial-sideband television systems serves to reduce this fault. It had also been understood[2] that the distorting out-of-phase component could be entirely eliminated in a synchronous detector whose beat oscillator is locked to the carrier frequency; but this solution seemed impractical at the time.

It would now appear that a very similar problem is being solved in the demodulator for the coloration subcarrier in color television. The essential step is to control the frequency and phase of a synchronous local oscillator by periodically comparing it with the received carrier at a time when that is unmodulated (or perhaps modulated by a known signal).

To suppress single-sideband distortion in television (monochrome or color) then requires the following steps, none of them at the transmitter:

1. Use a synchronous second detector, with a stable local oscillator at the nominal video IF carrier frequency.
2. Provide a gate circuit that opens when there is no modulation or a well-defined modulation, for instance during the color "burst."
3. During gate time compare the second LO in frequency and phase with the received IF carrier as it reaches the second detector.
4. The output of the comparison circuit then controls either the frequency of the second LO, or perhaps that of the first LO, so as to minimize the error.

Failure of the system, for instance during warm-up, will merely mean that single-sideband distortion remains as now.

The key to the control of the synchronous oscillator is, of course, the periodic comparison during the synchronizing periods, and any other transmission system that provides such periods of clean carrier can thus be made a single-sideband system without penalty of transient distortion.

Regarding transmission systems that do not provide regular synchronizing intervals, the question remains whether double-sideband transmission with its redundant waste of half the bandwidth is the only possible way to avoid single-sideband distortion. This is not the case. For instance:

1. In a single-sideband system, let there be transmitted two pilot frequencies so chosen and locked that their difference after demodulation is an exact measure of the transmitter carrier frequency; or
2. Transmit one pilot frequency so controlled by the whole modulation at the transmitter that after demodulation it yields an exact measure of the true transmitter carrier frequency; or
3. In systems where intervals without modulation are sufficiently frequent, even if irregularly spaced, let the gate select such periods for comparison.

Such methods would not now seem very attractive, except for particular applications. On the other hand, phase distortion in a sharply cutting single-sideband filter need not be feared; suitable filters are known.[3]

H. E. Kallmann
New York, N. Y.

[1] H. E. Kallmann, R. E. Spencer, and C. P. Singer, "Transient response of single-sideband systems," Proc. I.R.E., vol. 28, pp. 557–563; December, 1940.

[2] *Loc. cit.*, p. 560.

[3] H. E. Kallmann, "Transversal filters," Proc. I.R.E., vol. 28, pp. 302–310; July, 1940, (see Fig. 7).

Quasi-Fraunhofer Gain of Parabolic Antennas*

The gain of a parabolic antenna over an isotropic radiator may be defined as

$$G = \frac{4\pi P_m}{W}, \tag{1}$$

where W is the total radiated power and P_m is the maximum radiated power per unit solid angle in the axial direction of the paraboloidal reflector.

Let us assume that the wave is everywhere in-phase at the aperture plane of the considered parabolic antenna (Fig. 1). Since all the wavelets from various parts of the aperture plane do not arrive simultaneously at point P, a phase error exists which will effect the measured value of gain. However, for $R \geqq 2D^2/\lambda$, D being the aperture diameter, this phase error is small and the gain measured under this condition may approximate the true Fraunhofer gain, which is the value measured at $R\to\infty$.

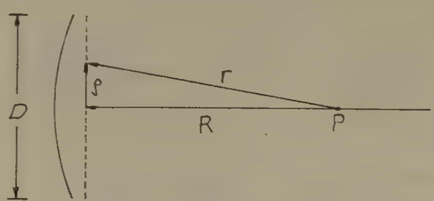


Fig. 1—Paraboloidal reflector.

In the practice of parabolic antenna design, tapered aperture illumination is employed for the reasons of optimum over-all efficiency and sidelobe reduction. Wavelets from regions near the edge of the aperture, which are largely responsible for the phase error, are now less weighted due to the tapering in the primary illumination toward the edge. It is the purpose of this note to show how the measured gain varies with R for several assumed tapered aperture illuminations. The transition region between the Fresnel and Fraunhofer regions, $D^2/4\lambda < R < 2D^2/\lambda$, is called Quasi-Fraunhofer region.

Assume that aperture illumination is:

$$E = E_0\left[1-\left(\frac{\rho}{a}\right)^2\right]^n, \tag{2}$$

where a is the aperture radius and n is the tapering constant. If $(\rho/R)^2 << 1$, then we find $r \cong R+\rho^2/2R$. Thus the field[1] at P is

$$E_p = j\frac{E_0}{\lambda R}e^{-jkR}\int_0^{2\pi}\int_0^a\left[1-\left(\frac{\rho}{a}\right)^2\right]^n \cdot e^{-jk\rho^2/2R}\rho\, d\phi\, d\rho, \tag{3}$$

where $k=2\pi/\lambda$. The corresponding radiation intensity at P is

$$P_m = \tfrac{1}{2}\eta R^2 |E_p|^2. \tag{4}$$

The total power radiated by the aperture is

$$W=\tfrac{1}{2}\eta E_0^2\int_0^{2\pi}\int_0^a\left[1-\left(\frac{\rho}{a}\right)^2\right]^n\rho\, d\phi\, d\rho. \tag{5}$$

The above integrations may be readily carried out for $n=0$, 1 and 2. On substituting (3), (4), and (5) into (1), we obtain

$$G = g_n 4\pi^2 a^2/\lambda^2,$$

where g_n is the gain factor with the following expressions for $n=0$, 1 and 2.

$$g_0=\frac{1}{K^2}[\sin K]^2$$

$$g_1=\frac{3}{K^4}[2+K^2-2\cos K-2K\sin K]$$

$$g_2=\frac{20}{K^6}\left[\left(1-\frac{K^2}{2}-\cos K\right)^2+(K-\sin K)^2\right],$$

in which $K = ka^2/2R$.

It is not difficult to show that, as $R\to\infty$, we have the true Fraunhofer gain

$$G_\infty = g_\infty\cdot\frac{4\pi^2a^2}{\lambda^2}=\frac{2n+1}{(n+1)^2}\,\frac{4\pi^2a^2}{\lambda^2}.$$

The normalized quantities g_0/g_∞, g_1/g_∞ and g_2/g_∞ are plotted in Fig. 2. It is noted that $n=0$ is the special case of uniform aperture illumination and the result is the same as that given by Silver.[1]

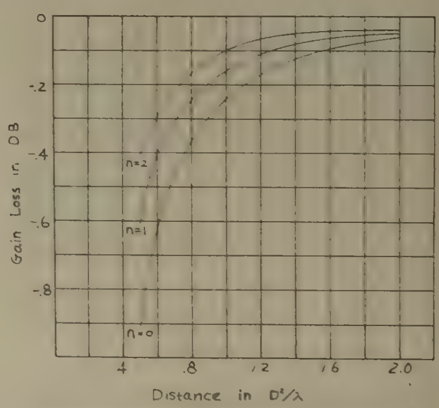


Fig. 2—Grain loss vs. distance for various tapered dish illuminations.

It is seen from Fig. 2 that, at a given distance, the error in the measured gain value is less for the tapered aperture illumination. If the primary feed pattern may be fitted into one of the family curves given by expression (2) for a large part of its major lobe, then Fig. 2 may be used as a correction curve to find the true Fraunhofer gain. This is permissible because the effects of the deviations between the hypothetical illumination [eq. (2)], and the practical primary feed pattern tend to average out in the process of integration.

Richard F. H. Yang
Andrew Corp.
Chicago 19, Ill.

* Received by the IRE, September 27, 1954.

[1] S. Silver, "Microwave Antenna Theory and Design," *Rad. Lab. Ser.*, vol. 12, pp. 198–199, McGraw-Hill Book Co., New York, N. Y.; 1949.

On Fourier Transforms in the Theory of Cathode-Ray Tubes*

It has been shown how Fourier Transforms can be used in a theory of determining the dynamic sensitivity of cathode-ray tubes at VHF.[1] Using the notations stated in the paper, the relative dynamic sensitivity of a cathode-ray tube is

$$\frac{A_d}{A_0} = \left| \frac{\int_{-b/2}^{b/2} \phi(x) e^{-j(2\pi x/\lambda_e)} dx}{\int_{-b/2}^{b/2} \phi(x) dx} \right|. \qquad (1)$$

The determination of the relative dynamic sensitivity at VHF may be divided into two steps:

1. Determinination of the static field strength distribution $E_y(x)$ along the x axis by either calculation or measurement when the forms of the plates are prescribed.

2. Determination of the sensitivity curve by means of the Fourier transform theory. As the electron velocity in the x direction is very nearly constant, $\phi(x)$ is proportional to $E_y(x)$, according to the equation

$$\phi(x) = \frac{d\varphi}{dx} \approx \frac{e}{mv_x^2} E_y(x). \qquad (2)$$

Knowing $\phi(x)$, the normalized Fourier transform immediately gives the relative dynamic sensitivity A_d/A_0, choosing a convenient length l of the field strength distribution.

Fig. 1 illustrates the well-known case of parallel plates neglecting stray fields and exit displacement.

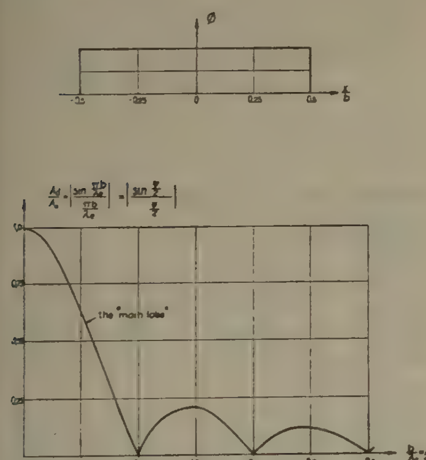


Fig. 1—The distributions of $\phi(x/b)$ and $A_dA_0(b/\lambda_e)$ in the parallel plates case.

In the same way as in the theories of antennas, inhomogeneous lines, time pulses, etc., a law equivalent to the uncertainty relation of Heisenberg determines the limits within which the distributions of the two Fourier transforms may vary. As is well known, the uncertainty relation has the following appearance for a particle with the momentum p in the x direction:

$$\Delta p \cdot \Delta x \approx h, \qquad (3)$$

where h = Planck's constant and the sign $\approx$ means "is proportional to and is of the order of . . . ."

Using the connection

$$= \frac{h}{\lambda}, \qquad (4)$$

we obtain the corresponding formula for waves:

$$\Delta \frac{1}{\lambda} \cdot \Delta x \approx 1. \qquad (5)$$

In the theory of cathode-ray tubes we get

$$\Delta \frac{1}{\lambda_e} \cdot \Delta x \approx \text{constant}, \qquad (6)$$

or

$$\Delta \frac{l}{\lambda_e} \cdot \Delta \frac{x}{l} \approx \text{constant}. \qquad (7)$$

Here $\Delta(l/\lambda e)$ = the width of the A_d/A_0 distribution, and $\Delta(x/l)$ = the width of the ϕ distribution. l must be constant in all cases to be compared.

As the electron velocity v_x is constant through the deflection field, (6) may be written

$$\Delta \frac{v_x}{\lambda_e} \cdot \Delta \frac{x}{v_x} \approx \text{constant} \qquad (8)$$

or

$$\Delta f \cdot \Delta \tau \approx \text{constant}, \qquad (9)$$

where τ is the electron transit time.

It is thus evident that the relative dynamic sensitivity is increased if the lengths of the plates are decreased, or if the electron velocity is increased. In the limiting case, when $\Delta\tau \to 0$, we obtain theoretically a field strength distribution in the form of a mathematical Dirac-pulse which corresponds to a horizontal A_d/A_0 distribution, i.e., a cathode-ray tube having the same relative sensitivity for all frequencies. However, at the same time the absolute sensitivity is approaching zero. This has been counteracted in modern cathode-ray tubes having small plates by using large distances between the plates and the screen and accelerating the electrons after deflection.

E. Folke Bolinder
Division of Radio Engineering
The Royal Institute of Technology
Stockholm, Sweden

* Received by the IRE, October 28, 1954.

[1] E. Folke Bolinder, "A theory of determining the dynamic sensitivity of cathode-ray tubes at very high frequencies by means of Fourier transforms," *Trans. I.R.E.* PGED, scheduled for early publication.

Intrinsic Barrier Transistor*

A new junction transistor, the p-n-i-p has recently been described.[1] Included in its structure is a thick collector-depletion layer of intrinsic (i-type) semiconductor. Theory predicted the extension of the useful frequency range of junction transistors by greatly reducing collector capacitance, while maintaining low ohmic base resistance and high collector breakdown voltage.

Transistors have recently been constructed using laboratory techniques which verify details of the theory. Alpha cutoff frequencies (f_α−3db) in the 50- to 100-mc range, collector capacitances in the 0.3 to 0.7mmf range, ohmic base resistances between 100 and 200 ohms, and collector breakdown voltages greater than 100 volts have been obtained. The best unit produced thus far oscillates stably at 465 mc.

As shown in Fig. 1, collector capacitance

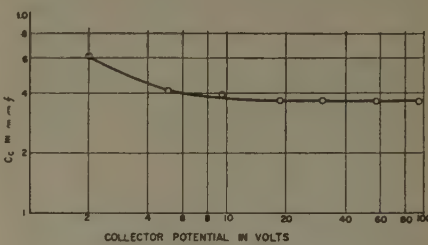


Fig. 1. p-n-i-p collector capacitance.

characteristically decreases with initial increase of collector bias and then becomes constant at higher voltage, as expected from theory. Collector reverse cutoff current (I_{co}), nominally below 20μa at 100v bias, increases 4.5 per cent per degree C. temperature rise. A concurrent study of small area p-i-n diodes with series ohmic resistances of less than 1 ohm showed a dynamic forward impedance of $2(kT/qI)$ (52 ohms at 1 ma). Again, this result agrees with theory.[2]

W. C. Hittinger, J. W. Peterson,
and D. E. Thomas
Bell Telephone Labs., Inc.
Murray Hill, N. J.

* Received by the IRE, October 29, 1954.

[1] J. M. Early, "*P-N-I-P* and *N-P-I-N* junction transistor triodes," *Bell Sys. Tech. Jour.*, vol. 33, p. 517; May, 1954.

[2] R. N. Hall, "Power rectifiers and transistors," Proc. I.R.E., vol. 40, pp. 1512–1518; November, 1952.

Checking Codes for Digital Computers*

There has been considerable interest recently in the representation of decimal digits in digital computers by binary expressions. The most general binary code consists of ten arbitrary binary expressions assigned to the decimal digits in some order. The most obvious code is the so-called 8421 code, which represents the decimal digit n by the number n written in the binary scale. A more useful code is the excess 3, which represents the decimal digit n by the binary number $n+3$. Its advantage is the property of nines—complementing by interchange of zeros and ones.

While the $n+3$ code is simple and useful, requiring only four binary digits, and having a simple addition rule in addition to the complementing property, it does not allow of a check. This letter reports the results of a study of checking codes made at the Moore School, University of Pennsylvania, in 1950–1951, on contract with the Burroughs Adding Machine Co., by Morris Plotkin and myself.

A "check," in the sense used here, is an examination of the expressions at a given point in the machine to determine whether

* Received by the IRE, November 12, 1954.

or not they belong to the code. If such an examination is to detect even a single error in a binary digit, the code must be so constructed that no code expression can be changed into another by a single error. It is convenient to define the "distance" between two binary expressions as the number of binary digits in which they differ. Thus, the expressions 1101 and 0011 are at distance three. A code is then said to be of distance d if the minimum distance between any two of its ten expressions is d. A code must, therefore, be of distance 2 or greater to qualify as a checking code. A code of distance d will give an alarm if $d-1$ or fewer errors occur simultaneously in a single expression.

The question then arises of constructing checking codes of distance 2, 3, etc., which retain the desirable addition and complementing properties of the $n+3$ code. It can be shown that a code must be of the form $an+b$ if addition is to be realizable through binary addition of the code expressions, with at most a constant additive correction (an additional correction is allowed in case of decimal carry). This requirement can be pictured as uniform spacing (with spacing n) of the code expressions in the list of consecutive binary numbers. The complementing property simply amounts to symmetrical spacing of the code expressions about the center line, for a given number of binary digits. Both points are illustrated in Table I, below, by the $n+3$ code, which is of distance 1, with four binary digits:

TABLE I

Decimal Digit n	$n+3$	Binary Expression
	0	0 000
	1	0 001
	2	0 010
0	3	0 011
1	4	0 100
2	5	0 101
3	6	0 110
4	7	0 111
5	8	1 000
6	9	1 001
7	10	1 010
8	11	1 011
9	12	1 100
	13	1 101
	14	1 110
	15	1 111

Naturally, it is desirable to use as few binary digits as possible in constructing a code. It is known that a code of distance 2 requires at least five binary digits, and a code of distance 3 at least seven. For the case of distance 2, the only five binary digit code with all properties is the 3 $n+2$ code. This code has the additional useful property of using all expressions of the form 3 $n+2$ in five binary digits, thus making for a simple checking process. Unfortunately, no comparable situation exists for distance 3 codes in seven binary digits—it is necessary to go to eight digits, making admissible the 27 $n+6$ code which has all properties, including the property of using all expressions of the form 27 $n+6$ in eight digits. But before dismissing the possibility of an acceptable distance 3 code in seven digits, several variations on the $an+b$ form were investigated, including codes whose expressions fall into two blocks of five each, with the same spacing in each block, and codes consisting of the 8421, excess 3, or 2421 nonchecking codes plus a three-digit check, which is added separately (though it is permitted to receive a carry correction). It was shown that no such possibility exists. Therefore, unless more complicated addition laws than the ones considered are found to be usable, the 27 $n+6$ code is the most desirable code of distance 3. It and the 3 $n+2$ code are believed to be new.

JOSEPH M. DIAMOND
United Transformer Company
150 Varick Street
New York 13, N. Y.

"Valve Noise Produced by Electrode Movement"*

With reference to the above paper,[1] a formula for cathode resonance following eq. (30) was given assuming 19.9×10^{11} dynes per square centimeter as Young's Modulus. This is the value at 20 degrees C. Since the cathode operating temperature is about 825 degrees C., the Young's Modulus corresponding to this temperature should be used.

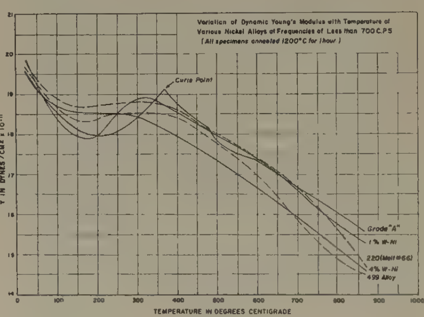


Fig. 1

As shown in Fig. 1, a considerable change in the Modulus occurs with increasing temperature. The curves shown are for grade "A" nickel, no. 220 alloy (melt #66), no. 499 alloy, 1 per cent and 4 per cent tungsten-nickel alloy.

Assuming a value of 15.25×10^{11} for no. 220 alloy at 825 degrees C., (30) reduces to:

$$f_{220} = \frac{1.24 \times 10^5 (r_1^2 + r_2^2)^{1/2}}{l^2}.$$

The specimens plotted on the curves were measured by the transverse vibration method. The specimens were made with a cross section and length for resonance at 500–700 cps. The effect of higher frequencies is to lower the dynamic modulus at elevated temperatures. As lower frequencies are used, the modulus approaches that obtained by static testing. The highest value of modulus at cathode-operating temperatures will be that of a single crystal. Fine-grained nickel appears to have a somewhat lower modulus.

I am indebted to Mr. Richard L. Hoff, Assistant Development Metallurgist, Superior Tube Company, Norristown, Pa., for this data and information.

JOHN J. GLAUBER
1800 North Huntington Street
Arlington 5, Va.

* Received by the IRE, June 6, 1954.

[1] P. A. Handley and P. Welch, "Valve noise produced by electrode movement," PROC. I.R.E., vol. 42, pp. 565–563; March, 1954.

Rebuttal[2]

In the derivation of the formula for calculating the resonant frequency of a cathode, reference was made to the original empirical relationship for the resonant frequency of nickel rods supported by mica insulators and the value of Young's Modulus at 20 degrees C. was used in the absence of further information.

We are indebted to Mr. Glauber for his graph showing the change in Young's Modulus with temperature. It is of interest that this change depends upon the type of cathode nickel used and that therefore the resonant frequency must be modified by the ratio of the square root of this value to that of the square root of 19.9×10 inches.

During our investigational work we have not observed the effects of cathode resonance and you will note that the noise frequency diagrams do not show them. For this reason we have concluded that the actual resonant frequency of cathodes in miniature valves is generally so high that it does not affect the valve performance in the same way as the lower frequency grid resonances and low frequency rattle noises. However, the fact that cathode resonance will be lower than that given by the empirical relation by about 10–15 per cent shows that this could be a source of trouble if long thin cathodes were used.

P. A. HANDLEY and P. WELCH
Brimar Valve Eng. Dept.
Standard Telephones & Cables Ltd.
Fortscray, Kent, Eng.

[2] Received by the IRE, July 15, 1954.

Russian Vacuum-Tube Terminology*

In a note under the above heading, on page 1023, vol. 42, of the June, 1954 PROCEEDINGS OF THE I.R.E., G. F. Schultz makes two statements which, to me, born and educated in Russia, appear not to be strictly correct.

The first statement is that "Russia has no 'h,' and this letter is commonly transliterated as Г (g) in words of non-Slavic origin." The Russian language has a letter corresponding to "h." It is "x," and can be seen as the first letter of the Russian equivalent for the word "characteristics," as given by Mr. Schultz; it is a soft "h," as in "home," and in this way different from the hard "x" or "chi" of the Greek.

The second is that "Russian has no equivalent to the English 'plate'." There is a Russian equivalent to the term "plate." It is "Пластинка," phonetically spelled "plastinka," and not infrequently found in Russian technical literature.

I. G. MALOFF
RCA
Camden, N. J.

* Received by the IRE, December 8, 1954.

Continuous Radar Echoes from Meteor Ionization Trails*

It is now established that there is a scattering medium in the E-region of the ionosphere which supports extended-range vhf radio propagation.[1,2] That is, when sufficient power is used, a substantially continuous signal can be propagated over medium distances (500 to 2000 km) at frequencies (30 to 100 mc) which are above the "maximum-usable-frequencies" of the regular ionospheric layers. The exact nature of the scattering process has never been adequately demonstrated. The principal theories offered in explanation of E-region scatter are: (1) scattering from "blobs" of ionization which may be created by turbulence;[1,3] and (2) overlapping of reflections from numerous meteor ionization trails.[2,4,5]

We are here proposing a simple experimental method of determining the relative contributions of (1) and (2) to E-region scatter. On the basis of measurements taken in a preliminary application of this method, we conclude that extended-range vhf propagation may be almost entirely supported by reflections from meteor ionization trails.

If the scattering medium consists of a horizontal layer of blobs formed by isotropic turbulence, the number of scatterers in a narrow radar antenna beam varies as R^3, where R is the range to the illuminated scatter region. (As used here, the term radar implies that the transmitter and receiver are at the same location.) The power scattered from each blob would vary as R^{-4}, so that the integrated power received from the illuminated region would be proportional to R^{-1}. Thus, the maximum radar response from blobs formed by isotropic turbulence would be obtained when the antenna beam is pointed vertically.

If the scattering medium consists of numerous meteor trails, the antenna elevation angle giving the strongest integrated radar echo is different from that required for blobs. The number of meteor trails illuminated by the narrow beam varies as R^3. These trails, being long and thin, produce strong echoes only when they are normal to a ray from the radar. The power reflected from an individual trail which is so oriented is proportional to R^{-3}. It has been shown that the number of properly-oriented trails in a limited volume of the E-region is dependent upon the location of this volume relative to the radar site.[4] In particular, very few meteor reflections can be obtained from an area directly over the radar, since there are very few horizontal meteor trails. The maximum number of properly-oriented trails per unit volume occurs in those areas of the E-region which are about 100 km away from the point over the radar site. It follows that the radar antenna beam should be elevated about 45 degrees from the horizontal to obtain the maximum integrated response from meteor ionization trails.

Weak radar echoes have been observed from what appears to be a scatter region by groups at Ottawa[6] and Saskatoon,[7] Canada. The relative effect of the elevation angle of the antenna beam was not studied by either group. The experimental results obtained at these locations, when considered in terms of the antenna effects outlined above, appear to provide conflicting evidence on the cause of the echoes. The possibility of auroral effects also makes it difficult to use these results to differentiate between meteoric and other types of scatter.

A number of attempts were made at Stanford University during the summer of 1953 to detect E-region scatter with a radar system. The frequency used in the Stanford tests was 23 mc, and the average radiated power was about 2 kw. Range gating, coherent detection, and narrow bandwidth were used in the receiver for increased sensitivity.[8] On those occasions when a high-gain, vertically-directed antenna was used, continuous scatter signals could not be detected at any range. On the other hand, continuous signals were readily observable when a fairly-broad antenna beam having maximum gain at an elevation angle of about 45 degrees was used. In this latter instance, the range gate was set to approximately 140 km.

In the experiments where the ever-present scatter echoes were recorded, strong individual meteor-bursts were very much in evidence. The remainder of the signal fluctuated randomly, as would be expected if it were due to the integrated effect of many small-amplitude, short-duration echoes occurring at random times. The characteristics of the continuous signal observed between the individually-discernible, larger meteor bursts is not of much help in explaining the nature of the scattering process, owing to the random nature of the integrated resultant whatever the causative agency. The fact that a continuous signal could not be obtained from overhead, whereas it could easily be obtained from more remote E-region areas, is regarded as evidence that overlapping meteor echoes were responsible for the total signal in the second case. From the wavelength and distance dependence of the signal amplitude measured in existing vhf propagation circuits,[9] and the dependence of meteoric reflections on wavelength and path length,[4] the conclusion is drawn that these preliminary radar results provide support for the view that meteoric ionization plays the dominant role in extended-range vhf propagation.

V. R. Eshleman, P. B. Gallagher and A. M. Peterson
Radio Propagation Lab.
Stanford University
Stanford, Calif.

* Received by the IRE, January 10, 1955. This work was supported by the U.S. Navy (Office of Naval Research), the U.S. Army Signal Corps, and the U.S. Air Force, Contract N6onr-251 Task 7.

[1] D. K. Bailey, R. Bateman, L. V. Berkner, H. G. Booker, G. F. Montgomery, E. M. Purcell, W. W. Salisbury, and J. B. Wiesner, "A new kind of radio propagation at very high frequencies observable over long distances," *Phys. Rev.*, vol. 86, pp. 141–145; April, 1952.

[2] O. G. Villard, Jr., A. M. Peterson, L. A. Manning, and V. R. Eshleman, "Extended range radio transmission by oblique reflections from meteoric ionization," *Jour. Geophys. Res.*, vol. 58, pp. 83–93; March, 1953.

[3] H. G. Booker and W. E. Gordon, "A theory of radio scattering in the troposphere," Proc. I.R.E., vol. 38, pp. 401–412; April, 1950.

[4] V. R. Eshleman and L. A. Manning, "Radio communication by scattering from meteoric ionization," Proc. I.R.E., vol. 42, pp. 530–536; March, 1954.

[5] D. W. R. McKinley, "Dependence of integrated duration of meteor echoes on wavelength and sensitivity," *Can. Jour. Phys.*, vol. 32, pp. 450–467; July, 1954.

[6] D. W. R. McKinley and P. M. Millman, "Long duration echoes from aurora, meteors, and ionospheric back-scatter," *Can. Jour. Phys.*, vol. 31, pp. 171–181; February, 1953.

[7] P. A. Forsyth, B. W. Currie, and F. E. Vawter, "Scattering of 56-mc/s radio waves from the lower ionosphere," *Nature*, vol. 171, pp. 352–353; February, 1953.

[8] P. B. Gallagher and A. M. Peterson, "Ionosphere sounding by cross-correlation techniques," paper presented at the Western Electronic Show and Convention, San Francisco, Calif.; August 21, 1953.

[9] D. K. Bailey, talk presented at the 11th General Assembly of URSI, The Hague, Netherlands; August 30, 1954.

"A Mathematical Technique for the Analysis of Linear Systems"*

Ragazzini and Bergen[1] have shown how the z-transformation can be applied to the analysis of linear systems. In their method, the time response of a feedback control system can be obtained fairly readily as the coefficients of the infinite series that results when the numerator of the system pulse transfer function is divided by the denominator. In obtaining the over-all pulse transfer function, the Laplace Transfer Function of the individual component blocks in the feedback loop must be known in factored form.

A relation exists, which has not, to the writer's knowledge, appeared in the literature, that permits one to check the derivation of a particular z-transform when the continuous transform is known. The relation is:

$$\lim_{T\to 0} TF^*(z) = F(S) \qquad (1)$$

where:

$$T = \text{Sampling Interval}$$
$$F^*(z) = Z\text{-transform}$$
$$F(S) = \text{Laplace-transform.}$$

This relation can be derived by noting that the Polygonal Approximation utilized[1] to the true time function approaches the true time function as the sampling interval approaches zero. The factor, T, is required in the equation to allow for the fact that the z-transform is based upon impulses of infinitesimal time duration rather than upon the generating triangles whose sum yields the Polygonal approximation.

The following example illustrates the use of (1). Given a z-transform that has been obtained by operation upon a time function:

$$F^*(z) = \frac{z}{z - \exp(aT)}. \qquad (2)$$

In this particular case, the function of time is $f(t) = \exp(at)$. Substituting (2) into (1), and utilizing the relation $z = \exp(ST)$ one has:

$$\lim_{T\to 0} \frac{T \exp(ST)}{\exp(ST) - \exp(aT)} = \frac{0}{0}. \qquad (3)$$

Applying L'Hospital's Rule:

$$\lim_{T\to 0} \frac{TS \exp(ST) + \exp(ST)}{S \exp(ST) - a \exp(aT)} = \frac{1}{S - a}. \quad (4)$$

The result of (4) is known to be the Laplace-transform of $f(t) = \exp(at)$.

Rubin Boxer
Rome Air Dev. Center
Air Res. & Dev. Command
Griffiss AF Base
Rome, N.Y.

* Received by the IRE, December 20, 1954.

[1] Proc. I.R.E., vol. 42, pp. 1645–1651; November, 1954.

High-Voltage Silicon Diodes*

Breakdown of a semiconductor junction diode is characterized by a rapid increase in back current as the applied reverse voltage increases slightly beyond some critical value. This value is such that the electric field across the junction, or parts of it, is sufficient to cause either Zener field emission or avalanche breakdown. The particular breakdown mechanism involved, as well as the magnitude of the critical voltage, depends on the semiconductor diode material, its resistivities, and the nature of the junction (step, linear gradient, etc.).

Although this paper is not concerned with the nature of the breakdown mechanism it should be noted that recent experimental evidence[1] indicates that the fields necessary for Zener emission are attainable only in narrow germanium junctions. Breakdown of broad germanium junctions and of silicon junctions in general is apparently of the avalanche type.

The high back resistance attainable in a properly made grown junction silicon diode, together with the superior temperature characteristics of silicon, make it an obvious choice for a "high voltage" diode. We shall arbitrarily list diodes with breakdown voltages in excess of one kilovolt in this class. Since the impurity distribution of a grown junction diode determines the magnitude of the breakdown voltage, the majority of the effort in such a project must necessarily be concentrated in the crystal growing stage where the impurity distribution is originally built in. For a given type of junction the breakdown voltage will, of course, be larger, the smaller the concentration of impurities (the higher the resistivity). However, it is important to realize that for an operational diode the forward resistance not only of the junction but of the entire unit must be kept as low as possible. Thus, the desired forward characteristics of the diode may set the upper limit on the resistivity.

When growing a junction crystal from the melt it is impossible to obtain a true "step" junction, at least as compared with that resulting from an alloy fusion process. However, when one considers the width of the space charge region at high reverse voltages, it becomes evident that this region is considerably wider than the junction itself, so that the abruptness of the original transition region (perhaps several tenths of a mil wide) becomes relatively unimportant. Calculations for one of the units discussed below indicate a space charge region width of 7 mils at a reverse voltage of 2.3 kilovolts. This is computed from the following expression:

$$d = \sqrt{2\epsilon(\mu_n\rho_n + \mu_p\rho_p)V} \text{ in M.K.S. units}$$

where

d = space charge width
ϵ = dielectric constant
$\mu_n\mu_p$ = drift mobilities of electrons and holes respectively
$\rho_n\rho_p$ = resistivities of the n and p regions respectively
V = applied reverse voltage.

* Received by the IRE, December 29, 1954. Supported in part by the Bureau of Ships, Department of the Navy, and the Signal Corps.

[1] K. G. McKay, "Avalanche breakdown in silicon," *Phys. Rev.*, vol. 94, pp. 877; May 15, 1954.

This is obtained directly from solution of Poisson's equation for a step junction.

From the above argument it might seem that the distinction between the "step" and "graded" junctions was entirely meaningless as regards high-voltage diodes. This, however, is not true, as the concentration gradients across the junction regions can be varied over such wide limits that the breakdown behavior differs considerably between the two types of junctions, even at high reverse voltages.

With these design criteria as a guide, an attempt was made to assess the practical possibilities of high-voltage grown-junction silicon diodes. Several high-resistivity junction crystals were grown and sliced into bars of suitable dimensions. Low resistance ohmic contacts were made to the ends of these bars. Various etching and surface techniques were used, and the best ones selected. The following figures will show the characteristics of two of these experimental units, which were contained in glass envelopes filled with an inert atmosphere.

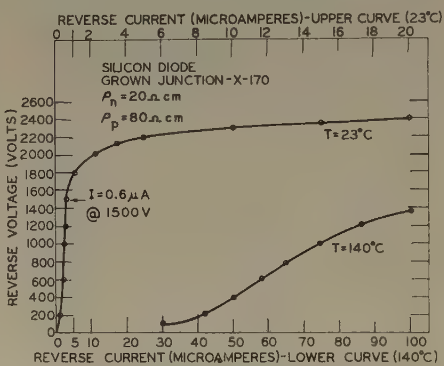


Fig. 1

Fig. 1 shows the reverse characteristics of a silicon step junction diode with resistivities of 80-ohm/cm on the p side and 20-ohm/cm on the n side. Data were taken at room temperature and at 140 degrees C., and were plotted on a linear scale to show detail in the high-voltage region. Points of interest on the room temperature curve (upper abscissa) include the 2,500 megohm resistance at 1,500 volts and breakdown at 2,300 volts. At 140 degrees C., the unit still exhibits better than 20 megohms of back resistance at 1,400 volts. The diode was about 50 mils square in cross section, so that the abscissas should be multiplied by about 50 to get the current density. (1 ma/cm² full scale for the upper abscissas, 5 ma/cm² full scale for the lower.)

Fig. 2 shows the forward characteristics of the same diode. The forward current was the same at 140 degrees C. as at room temperature. The forward resistance above 2 volts is lower than that of the 5V4G high vacuum rectifier, which is an indirectly heated cathode type. Of course, in terms of replacement possibilities, it must be pointed out that the 5V4G is a full wave rectifier and will pass 175 ma of forward current at a dissipation of 4 to 5 watts. The silicon laboratory diode discussed here is outclassed in this respect at this point.

Fig. 3 shows the result of measurements of an interesting diode. This unit was cut from a crystal of 40 ohm/cm resistivity for both the p and n side. Its concentration gradient differs from that of the first unit shown in that it is a "graded" junction. With this unit, even though the resistivities are of the same order of magnitude as those of the step junction, one would expect a higher breakdown voltage. Various surface treatments were necessary before it became possible to obtain data at the highest voltages.

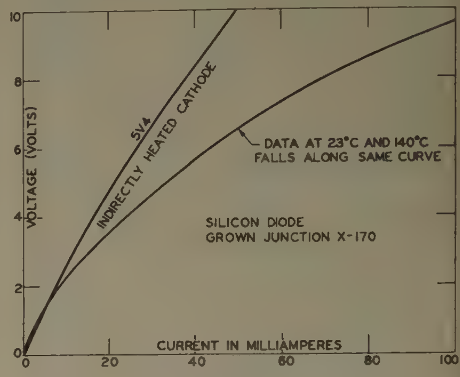


Fig. 2

The highest such point corresponds to less than 6 microamps at 5,300 volts. Above this voltage, a region of what was believed to have been surface instability was found. In this region, the readings were not reproducible, i.e., the currents of 12 and 16 microamps corresponding to 5,500 and 5,700 volts respectively could change by as much as 100 per cent from one instant to the next. The location of this unstable region was very much a function of the surface treatment. It is assumed that instability of surface prevented observation of a junction breakdown.

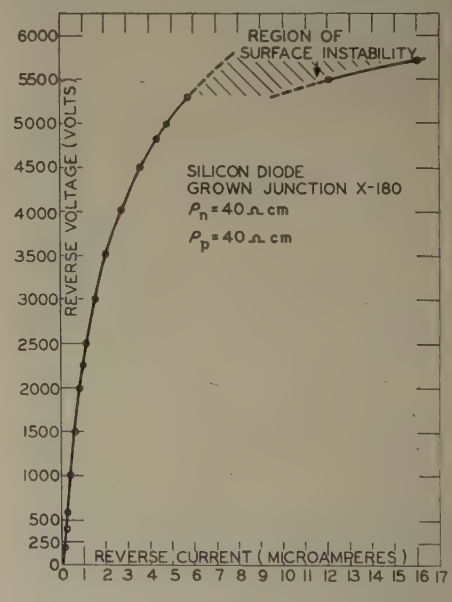


Fig. 3

It may thus be seen that an extension of the useful range of junction diodes has been made possible through the use of high-resistivity silicon junctions. For the first time, high-voltage characteristics are obtainable in a single unit solid-state rectifier such that the device becomes comparable to high-vacuum rectifier tubes.

L. G. Rubin and W. D. Straub
Raytheon Mfg. Co.
Waltham, Mass.

Contributors

W. R. Beam (A'50) was born in Richmond, Va., on August 27, 1928. He received the B.S. degree in 1947, the M.S. in 1950, and the Ph.D. in 1953, in electrical engineering, all from the University of Maryland. He was an instructor in electrical engineering at the University of Maryland from 1947 to 1952, and from 1947 to 1949 was also associated with Washington Institute of Technology, Inc.

W. R. Beam

Since 1952, he has been a member of the technical staff at Radio Corporation of America, RCA Laboratories.

Dr. Beam is a licensed P.E. in New Jersey and a member of Tau Beta Pi and Sigma Xi.

❖

H. N. Dawirs (S'49–A'52) was born in Colorado, on July 10, 1920. He received his B.S. in electrical engineering in 1942 from Colorado State College of Agriculture and Mechanic Arts, and his M.S. in mathematics from Ohio State University.

H. N. Dawirs

From 1942 to 1946 Mr. Dawirs worked in the engineering departments of a number of Westinghouse plants. From 1946 until 1948 he worked in the research department of the Curtiss Wright Corp., Columbus plant. Since 1948 he has been with the Antenna Lab. of Ohio State University Research Foundation.

He is a member of Pi Mu Epsilon.

❖

O. Doehler was born on January 27, 1913, in Schwarzenbek, Germany. He studied from 1932 to 1938 at the University of Hamburg and received his Doctorate from the Institute of Applied Physics. From 1938 to 1945 he was an assistant professor at the Institute of Applied Physics, where he worked on the development of microwave tubes.

O. Doehler

In 1946 he joined the Compagnie Générale de Télégraphie Sans Fil, where he has been conducting theoretical and experimental studies on traveling-wave tubes.

❖

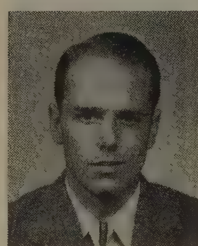
Bernard Epsztein was born in Paris, France, on November 28, 1924. He received the Licence ès Sciences in 1947 from Paris University. That year, he joined the Compagnie Générale de Télégraphie Sans Fil where he has been engaged in research work on microwave tubes, especially high power klystrons, T.P.O.M. (magnetron amplifiers) and Carcinotron tubes.

B. Epsztein

Mr. Epsztein is a member of the Société Française des Radioélectriciens.

❖

T. E. Everhart was born in Kansas City, Missouri, on February 15, 1932. He received a B.A. degree in physics from Harvard College in June, 1953, and immediately after graduation became a member of the Hughes Research and Development Laboratories Cooperative Plan for Master of Science degrees.



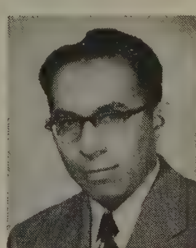
T. E. Everhart

At Hughes, he has been engaged in traveling-wave tube research. In January, 1955, he received a M.S. degree in applied physics from U.C.L.A.

He is a member of Phi Beta Kappa and an associate member of Sigma Xi.

❖

A. D. Fialkow was born in New York, N. Y., on August 9, 1911. He received his B.S. and M.S. degrees from City College of New York. At Columbia University, he was University Scholar and University Fellow and received the Ph.D. degree in mathematics.



A. D. Fialkow

He has done research at Federal Telephone and Radio Laboratories, and Control Instrument Co. At present, he is professor of mathematics at Brooklyn Polytechnic Institute.

Dr. Fialkow is a member of the American Mathematical Society, Phi Beta Kappa and Sigma Xi.

❖

I. Gerst was born in New York, N. Y., on May 30, 1912. He received the B.S. degree from the City College of the City of New York in 1931 and the M.A. and Ph.D. degrees in mathematics from Columbia University in 1932 and 1947. He taught mathematics in the New York City school system from 1937–1942.

I. Gerst

Since 1946 he has been research mathematician and then head of the mathematics section at Control Instrument Company, Brooklyn, N. Y.

Dr. Gerst is a member of the American Mathematical Society, the Mathematical Association of America, Phi Beta Kappa and Sigma Xi.

❖

L. J. Giacoletto (S'37–A'42–M'44–SM'48) was born in Clinton, Ind., on November 14, 1916. He received the B.S. degree in electrical engineering from Rose Polytechnic Institute, Terre Haute, Ind., in 1938; and the M.S. degree in physics from the State University of Iowa in 1939. He received his Ph.D. degree in electrical engineering from the University of Michigan in 1952.

L. J. Giacoletto

Since June, 1946, he has been a research engineer with the RCA Laboratories, Princeton, N. J.

Dr. Giacoletto is a member of the American Association for the Advancement of Science, Gamma Alpha, Iota Alpha, Phi Kappa Phi, Tau Beta Pi, and Sigma Xi.

❖

P. R. Guénard (SM'50–F'55) was born on January 22, 1914, in Amiens, France. As a student at the Ecole Normale Supérieure, Paris, he received the Licence ès Sciences in 1935 and the Agrégation des Sciences Physiques in 1937. He joined the Compagnie Générale de Télégraphie Sans Fil in 1942, where he was engaged in research work on microwave tubes. In 1948 he became head of a research laboratory on microwave tubes. Recently he has been appointed assistant director of the Department Electronique of the C.S.F.

P. Guénard

He is a member of the Société Française de Physique, Société française des Electriciens, Société des Radioélectriciens and Société Française des Ingénieurs Techniciens du Vide. In 1952, he received the Prix d'Aumale de l'Académie des Sciences.

S. R. Lederhandler was born in Astoria, N. Y., on March 19, 1927. He received the B.E.E. degree in 1951 from Rensselaer Polytechnic Institute. From 1951 to 1953 he did graduate work under a bioelectrical fellowship, serving also as an instructor. He received the M.E.E. degree in 1953 from Rensselaer, where he continued his doctoral studies having been awarded an R.P.I. fellowship.

S. LEDERHANDLER

Mr. Lederhandler is now associated with the research division of Raytheon Manufacturing Co.

He is a member of Sigma Xi and Eta Kappa Nu.

❖

W. H. Louisell was born in Mobile, Ala., on August 22, 1924. He received his Ph.D. degree in physics from the University of Michigan in 1953.

W. H. LOUISELL

He was a member of the U. S. Army from 1943 to 1946, and was associated with the Engineering Research Institute, University of Michigan from 1948 to 1953. Since June, 1953 he has been a member of the technical staff at the Bell Telephone Laboratories, Murray Hill, N. J.

Dr. Louisell is a member of Sigma Xi, Phi Kappa Phi, and the American Physical Society.

❖

C. W. Lufcy was born in Puxico, Mo., on December 11, 1920. He received an A.B. degree from the Southeastern Missouri State College in 1942 and an M.S. in physics from the Illinois Institute of Technology in 1944. He worked at the latter institution as a research associate in electron microscopy while doing graduate work. He was honorably discharged from the Navy in 1945, after which he served as head of the Physics Department at the Southeastern Missouri State College.

C. W. LUFCY

He joined the Naval Ordnance Laboratory, White Oak, Md., in 1947, and he set up an electron microscope and mass spectrometer facility there. Upon completion of this work he transferred to the magnetics division in 1949 to take charge of the applied research program on magnetic amplifiers. In 1952 he was made chief of the magnetics division.

Mr. Lufcy is an associate member of the American Institute of Electrical Engineers and a member of Sigma Xi.

❖

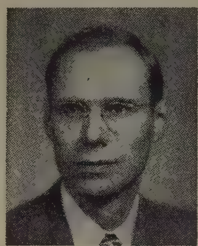
For a photograph and biography of A. B. Macnee, see page 1026 of the June, 1954 issue of the PROCEEDINGS OF THE I.R.E.

❖

For a photograph and biography of A. R. Moore, see page 1026 of the June, 1954 issue of the PROCEEDINGS OF THE I.R.E.

❖

J. R. Pierce (S'35–A'38–SM'46–F'48) was born in Des Moines, Iowa, on March 27, 1910. He received his Bachelor's and Master's degrees in electrical engineering from the California Institute of Technology in 1933 and 1934 respectively. In 1936 he received his Ph.D. degree from the same institution.



J. R. PIERCE

Since 1936 he has been a member of the technical staff of the Bell Telephone Laboratories, Inc., where he has been concerned with various vacuum-tube problems. In January, 1952, he became director of Electronics Research at Bell Laboratories.

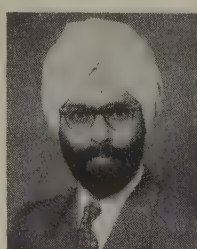
In 1948 Dr. Pierce received the IRE Fellow Award for his "many contributions to the theory and design of vacuum tubes."

Dr. Pierce is the recipient of the Eta Kappa Nu "Outstanding Young Electrical Engineer" award for 1942, and the IRE Morris Liebmann Memorial Prize for 1947. Dr. Pierce is the author of two widely known books in his field, *Theory and Design of Electron Beams*, and *Traveling Wave Tubes*, and in addition has written many popular science articles for various magazines.

He is a Fellow of the American Physical Society, and a member of the American Institute of Electrical Engineers, the British Interplanetary Society, Tau Beta Pi and Sigma Xi. He is Editor of the PROCEEDINGS OF THE I.R.E. and a Director of the I.R.E., 1954–1955.

❖

A. Singh received his M.S. degree in physics from Punjab University in 1945. Following this he was sent to the United States on a Government of India Scholarship. He received a Master of Engineering Science degree in 1947, and a Ph.D. in 1949, both from Harvard University.



A. SINGH

Dr. Singh was a lecturer in radio physics at the University of Delhi from 1949 to 1953. Since 1953 he has been a scientific officer with the National Physical Laboratory of India.

T. E. Talpey (S'47–A'50–M'53) was born on March 20, 1925, in Auburn, N. Y. He received the B.E.E. degree from Cornell University in 1946 and the M.S. and Ph.D. degrees in electrical engineering from the University of Michigan in 1948 and 1954. In 1951 he was awarded a Fulbright grant to study at the University of Grenoble, France, where he obtained the Doctorat d'Université in 1952.

T. E. TALPEY

From 1946 to 1953, he was an instructor in the Department of Electrical Engineering at the University of Michigan. In July, 1953 he joined the technical staff of the Bell Telephone Laboratories, Murray Hill, N. J., where, as a member of the Electron Tube Development Department, he has been engaged in the study of noise in grid-control tubes.

Dr. Talpey is an associate member of the AIEE and a member of Sigma Xi, Tau Beta Pi, Eta Kappa Nu and Phi Kappa Phi.

❖

R. R. Warnecke (SM'48–F'50) was born on November 16, 1906, at Tours, France. He received the degree of Docteur de l'Université in Paris in 1933. Following this he became chief of the vacuum tube laboratory of the Société Française Radioélectrique; in 1940 he was head of the electronic tube research laboratory of the Compagnie Générale de Télégraphie Sans Fil and, in 1946, chief engineer at the research center of this company. He is now technical director of the Electronics Department in the same organization.

R. R. WARNECKE

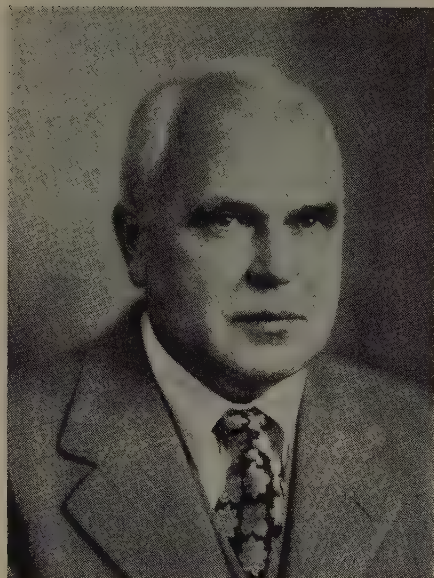
Dr. Warnecke is a member of the Société Française de Physique, the Société Française des Electriciens, the Société des Radioélectriciens, and the Société des Ingénieurs et Techniciens du Vide. He received the IRE Fellow award in 1950 for "his engineering and research contributions to vacuum-tube theory and design in France." Dr. Warnecke also received the Prix Ancel of the Société Française des Electriciens in 1943, the Prix H. Becquerel de l'Académie des Sciences de Paris in 1945, the Blondel Medal in 1951, and the Prix d'Aumale de l'Académie des Sciences de Paris in 1952. In 1954, he was the recipient of the Morris Liebmann Memorial Prize Award.

❖

For a photograph and biography of W. M. Webster, see page 346 of the March, 1955 issue of the PROCEEDINGS OF THE I.R.E.

IRE Awards, 1955

Medal of Honor Award



HARALD T. FRIIS

For his outstanding technical contributions in the expansion of the useful spectrum of radio frequencies, and for the inspiration and leadership he has given to young engineers.

Morris Liebmann Memorial Prize

ARTHUR V. LOUGHRIN

For his leadership and technical contributions in the formulation of the signal specification for compatible color television.

Browder J. Thompson Memorial Prize

BLANCHARD D. SMITH, JR.

For his paper entitled, "Coding by Feedback Methods," which appeared in the August, 1953 issue of the PROCEEDINGS OF THE I.R.E.

Harry Diamond Memorial Award

BERNARD SALZBERG

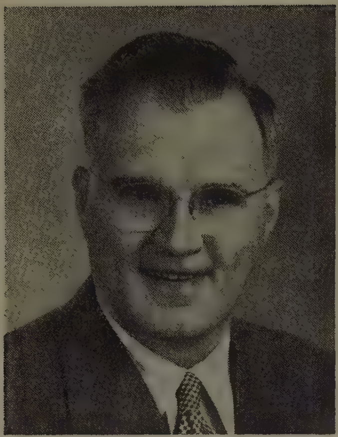
For his contributions in the fields of electron tubes, circuits, and military electronics.

Vladimir K. Zworykin Television Prize

HAROLD B. LAW

For development of techniques and processes resulting in a practical form of shadow-mask tri-color kinescope.

New Fellows



V. J Andrew

For his contributions to radio antennas and transmission lines.

R. M. Ashby

For his contributions to radar detection theory and integration of fire control-flight control systems for aircraft.

C. H. Bachman

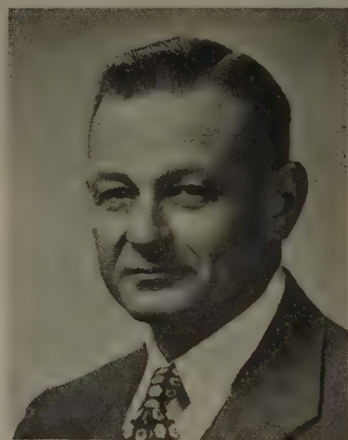
For his contributions in the field of electron physics.

G. I. Back

For his leadership in the field of military communications and communication systems.

B. G. Ballard

For his direction of radar and electronic research in Canada.



G. S. Brown

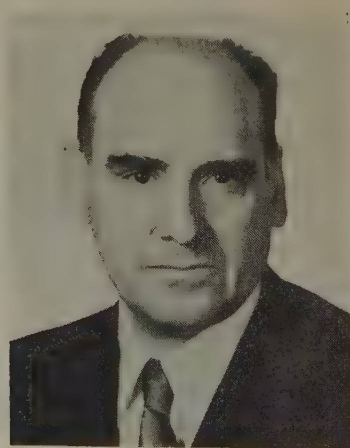
For his contributions to automatic control systems and to engineering education.

G. H. Browning

For his early contributions and his inspirational leadership in the electronics field.

Kenneth Bullington

For his contributions to the field of radio propagation.



V. S. Carson

For his contributions to the development and analysis of long-range aeronautical electronic navigation systems.

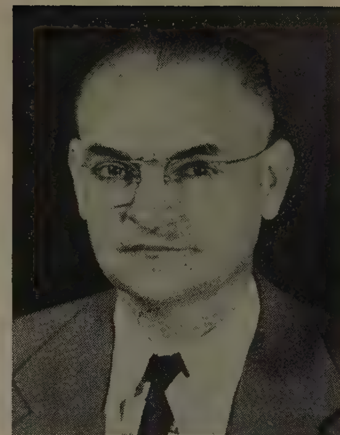
New Fellows

J. A. CHAMBERS

For his contributions to the development of high power broadcast transmitters and military electronic equipment.

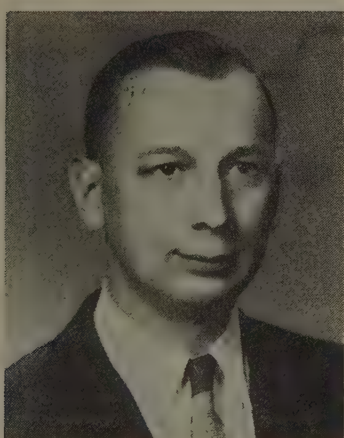
R. D. CHIPP

For his contributions to the development of radar and television apparatus for the Navy.



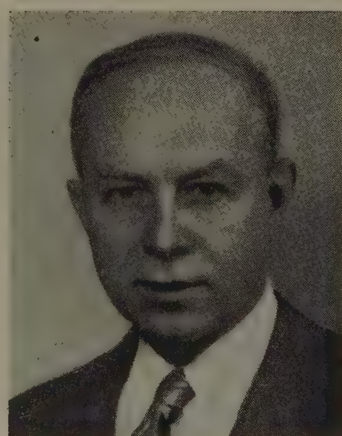
C. E. CLEETON

For his contributions to microwave spectroscopy and electronic identification systems.



J. W. COLTMAN

For his contributions to the fields of microwave techniques, X-ray applications, and nuclear studies.



A. G. COOLEY

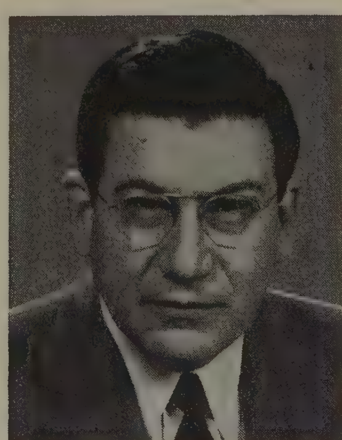
For his contributions to facsimile transmission methods.

F. A. COWAN

For his contributions to long-distance communication, particularly in the development of television network facilities.

C. C. CUTLER

For his research on microwave antennas and tubes.



HARRY DAVIS

For his contributions to the development of electronic aerial navigation systems.

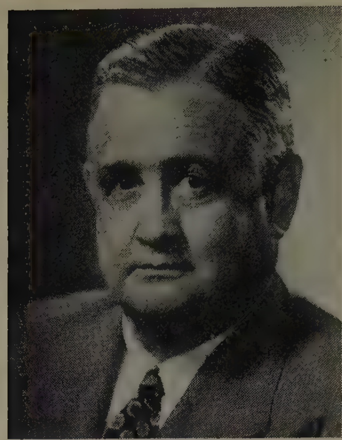
J. W. DAWSON

For his contributions to the advancement of scientific and engineering knowledge.

New Fellows

R. L. Dietzold

For his application of mathematics to network design and military problems.



C. S. Draper

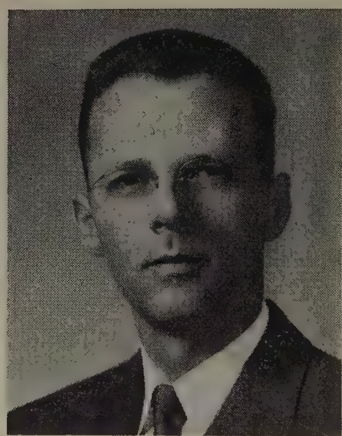
For his contributions to the theory and practical application of precise instrumentation and to engineering education.

O. M. Dunning

For his contributions to the field of sound recording, and his effective organization of engineering effort.

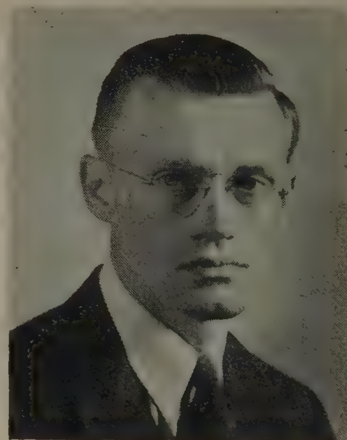
J. B. Fisk

For his contributions to the development of the magnetron and his leadership in basic electronic research.



J. W. Forrester

For his contributions to the development and engineering design of high speed digital computers.



G. L. Fredendall

For his applications of network analysis and synthesis to television system problems.

F. J. Gaffney

For contributions to the field of electrical measurements.

R. S. Glasgow

For his contributions to the field of engineering education.

Harold Goldberg

For his contributions to the field of guided missile armament.

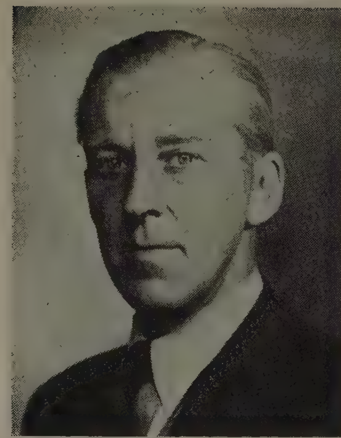
New Fellows

T. E. Goldup

For his pioneering achievements in the design and development of thermionic tubes and his contributions to the technical and administrative counsels of the British radio industry.

A. W. Graf

For his contributions to the radio engineering profession.



C. E. Granqvist

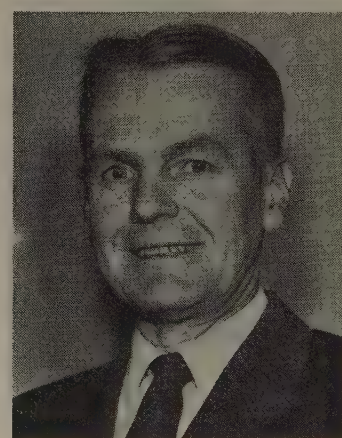
For his contributions to air navigation systems and devices, and for his leadership in the engineering of electronic apparatus.

E. I. Green

For his contributions in the development of communication systems and apparatus components.

P. R. Guénard

For his scientific and technical contributions in the field of microwave tubes.



W. A. Harris

For his contributions to the development of frequency converter tubes and to the understanding of fluctuation phenomena in electronic tubes.

A. E. Harrison

For his contributions as a teacher, author and engineer, especially in the field of klystrons.

Gerhard Herzog

For his contributions to radioactive instrumentation for geological survey and medical applications.

S. C. Hight

For his contribution to communication and weapon systems development.

New Fellows

G. W. O. Howe

For his pioneering work in radio and his outstanding contributions to engineering education.

L. A. Hyland

For contributions to aircraft radio direction finding, and his effective direction of research.

R. B. Janes

For his contributions to the development of improved camera tubes.

Martin Katzin

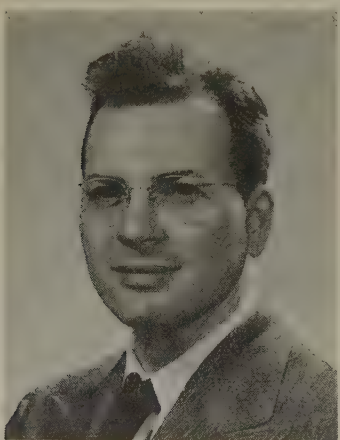
For his contributions to the knowledge of microwave propagation.

V. R. Learned

For his contributions to research and development of microwave electron tubes.

E. A. Lederer

For his contributions to the application of chemical and metallurgical science to electron tubes.



Meyer Leifer

For his contributions to the fields of electronic navigation and information theory.

T. M. Libby

For his technical contributions and long service in the field of communications.

Urner Liddel

For his contributions to the establishment, promotion and integration of government sponsored nuclear research in academic institutions.

New Fellows

E. G. Linder

For his contributions to microwave electronics.

B. D. Loughlin

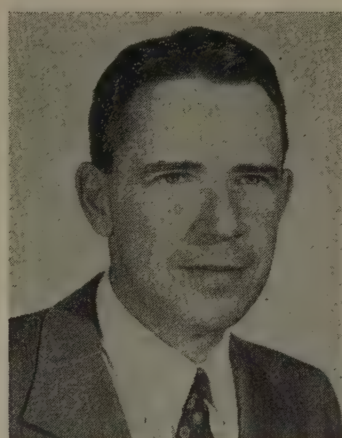
For contributions to color television, frequency modulation, and superregeneration.

C. J. Marshall

For his contributions to airborne television and radar research and development.

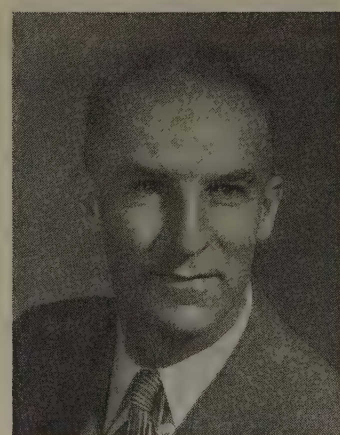
R. E Moe

For his contributions to the field of electronics.



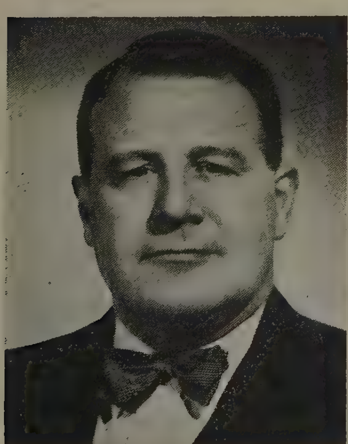
R. C. Moore

For his contributions to television circuitry.



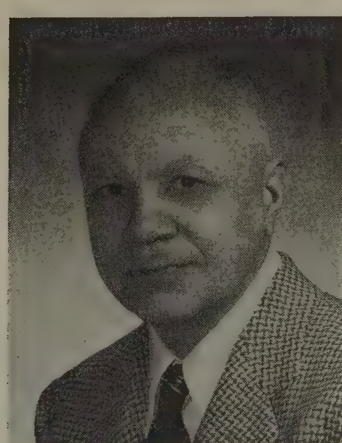
P. L. Morton

For his contributions to the field of digital computers and the teaching of electronics.



W. A. Nichols

For his contributions to the construction of the national radio system in Canada.



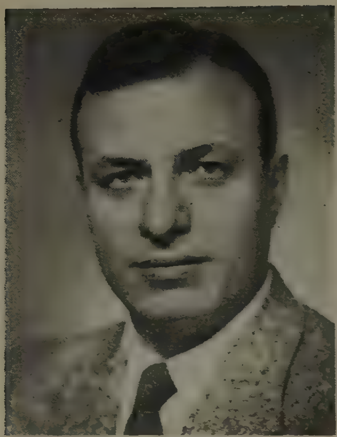
R. S. Ohl

For his contributions to the development of solid state point contact rectifiers

W. H. Pickering

For his contributions as teacher of electronics, and for his leadership in missile guidance, control and instrumentation.

New Fellows



J. R. Ragazzini

For his contributions in the fields of computers and control systems and as a teacher of these subjects.

E. G. Ramberg

For his theoretical analyses of electronic devices.

W. G. Richardson

For his contributions to the art of broadcasting, both sound and television, in Canada.

L. N. Ridenour

For his stimulating leadership in the field of electronic engineering.

H. E. Roys

For his contributions to the improvement of disk and tape recording.

O. H. Schmitt

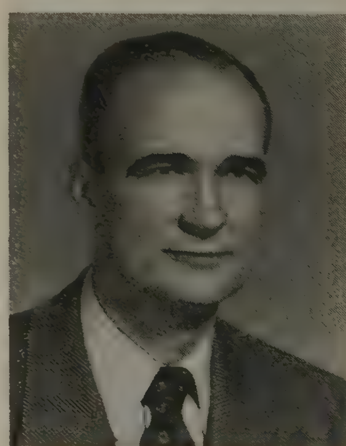
For his contributions to the application of electronics to the study of living organisms.

B. A. Schwarz

For his contributions to the development and production of automobile radios.

Samuel Seely

For his contributions as an educator, author and as a director of research and development.



William Shockley

For his contributions to development of the transistor.

New Fellows

C. M. Sinnett

For his contributions in the field of electronic circuitry.

C. E. Smith

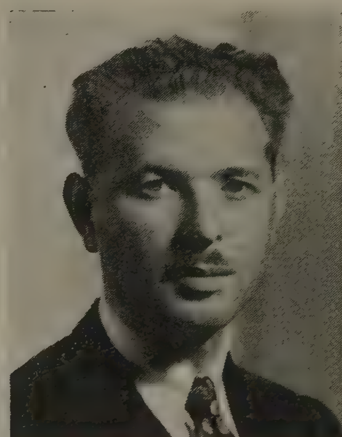
For his contributions to broadcast engineering and for his training activities.

J. E. Smith

For his contributions to the art of radio communications.

P. L. Spencer

For his contributions to the design and development of electron tubes.

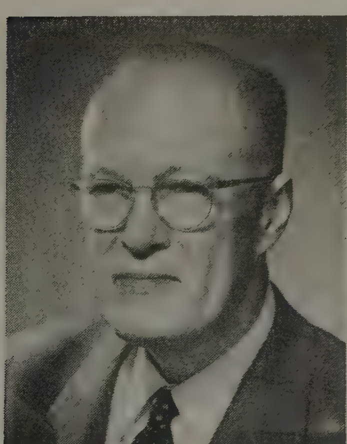


G. C. Sziklai

For his contributions to television circuits and systems.

B. D. H. Tellegen

For his contributions and teachings in the field of vacuum tubes and communication networks.



J. R. Tolmie

For his early contributions to radio.

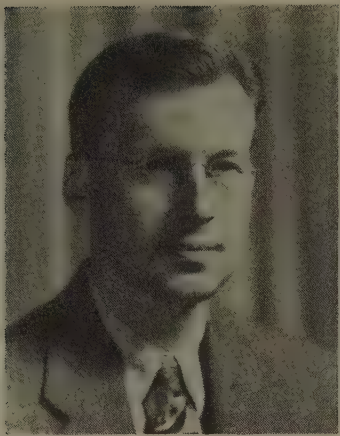
W. G. Tuller (deceased)

For his contributions to the advance of theoretical analysis of information theory and its practical application.

C. H. Vollum

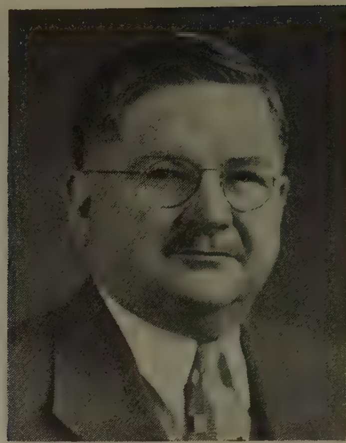
For his contribution to the development and manufacture of electronic laboratory instruments.

New Fellows



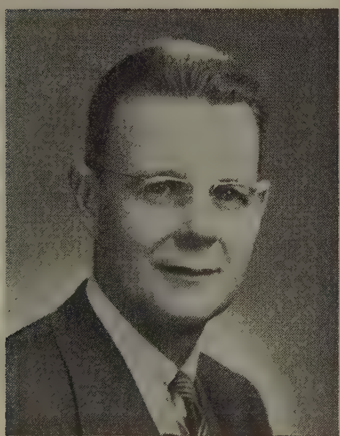
P. K. WEIMER

For his contributions to the development of television pickup tubes.



E. L. WHITE

For his leadership in advancing the use of radio in the interest of safety and efficiency in industry.



A. J. WILLIAMS, JR.

For his contribution to the field of self-balancing recorders of electrical quantities.

R. D. WYCKOFF

For his contributions to geophysical instrumentation, and the development of guided missiles.

IRE News and Radio Notes

IRE Grants Membership Leave to Members in Armed Service

At the January meeting, the Board of Directors voted on a policy to grant leave of absence from IRE membership to those in the Armed services. The leave will be granted, upon written request to IRE Headquarters, for a period up to three and one half years.

The member will have an inactive status during this period; he will not be required to pay dues, nor will he receive the PROCEEDINGS, or have other privileges of membership. When the member is discharged from service, he will be restored to the position he held preceding leave of absence. If Headquarters does not receive notice at the end of the three and one half year absence period, restoration to active membership will be made automatically.

Nuclear Engineering Conference to Meet in California

From April 27 to 29 a Conference on Nuclear Engineering will be held at University of California Los Angeles Campus.

A panel discussion will be featured each day of the conference: "Water and Liquid Metals as Primary Working Fluids," "Radiation Sources for Industrial Applications," and "Power Reactor Control During Load Changes." At an evening dinner session on April 28, John von Neumann, Institute for Advanced Studies, will speak.

The conference is sponsored by the UCLA Department of Engineering; Nuclear Engineering Division, AIChE; Southern California Section, ASME; Southern California Section, AIChE; Golden Gate Chapter, ASM; San Francisco Section, AIEE; and Northern California Section, AIChE. Further information may be obtained from the University of California Extension, Los Angeles 24, California.

Automation Symposium to Meet at Michigan State in May

The Engineering School of Michigan State College will sponsor a symposium called "Automation—Engineering for Tomorrow" on May 13. A part of the college's centennial year activities, the symposium will present general sessions, of interest to all branches of engineering, and special meetings, each presented by different departments and of interest to specific engineerings fields.

Among the symposium speakers, will be W. R. G. Baker, Vice-President of the General Electric Company, and Eric A. Walker, Dean of Engineering at Pennsylvania State University. Dr. Baker will look at automation from a technical point of view, while Dean Walker will discuss it from the philosophical and sociological standpoint. Included for discussion at the general sessions are: Automatic Control Systems; Design of Systems; and Instrumentation of Automation.

Further details may be obtained from Prof. J. M. Apple, School of Engineering, Michigan State College, East Lansing, Michigan.

PGANE and Dayton Section Honor Dayton Univ.

Dayton University is honored for its support of the Dayton Section and PGANE of Dayton. From left to right, J. H. Parr and L. H. Rose, both of the university, receive scroll and set of MIT Radiation Laboratory Series from A. B. Henderson and P. G. Wiegert, the Chairmen of the Dayton Section and of Dayton PGANE respectively.

Calender of Coming Events

IRE-PIB Symposium on Modern Network Synthesis, Engineering Societies Building, New York, N. Y., April 12–15

Instrumentation Symposium, Proving Ground Instrumentation Committee of the American Ordnance Association, Patrick Air Force Base, Cocoa, Florida, April 14 and 15

IRE 9th Annual Spring Technical Conference, Cincinnati, Ohio, April 15–16

SMPTE 77th Semiannual Convention, Hotel Drake, Chicago, Ill., April 17-22

International Symposium on Electrical Discharges in Gases, Technical University, Delft, Netherlands, April 25–30

IRE Seventh Region Technical Conference and Trade Show, Hotel Westward Ho, Phoenix, Ariz., April 27–29

New England Radio Engineering Meeting, Sheraton Plaza Hotel, Boston, Mass., April 29–30

Semiconductor Symposium, Electrochemical Society, Cincinnati, Ohio, May 2–5

IRE URSI Spring Meeting, Washington, D. C., May 3–5

National Aeronautical Electronics Conference, Biltmore Hotel, Dayton, Ohio, May 9–11

IRE-AIEE-IAS-ISA National Telemetering Conference, Hotel Morrison, Chicago, Ill., May 18–20

AFCEA Global Communications Convention, New York City, May 19–21

IRE-AIEE-RETMA-WCEMA Electronic Components Conference, Hotel Ambassador, Los Angeles, Calif., May 26–27

American Society for Engineering Education Annual Meeting, Pennsylvania State University, State College, Pennsylvania, June 20–24

URSI-U. of Michigan International Symposium on Electromagnetic Wave Theory, University of Michigan, Ann Arbor, Mich., June 20–25

IRE-AIEE Conference on Industrial Electronics, Rackham Memorial Building, Detroit, Michigan, September 28–29

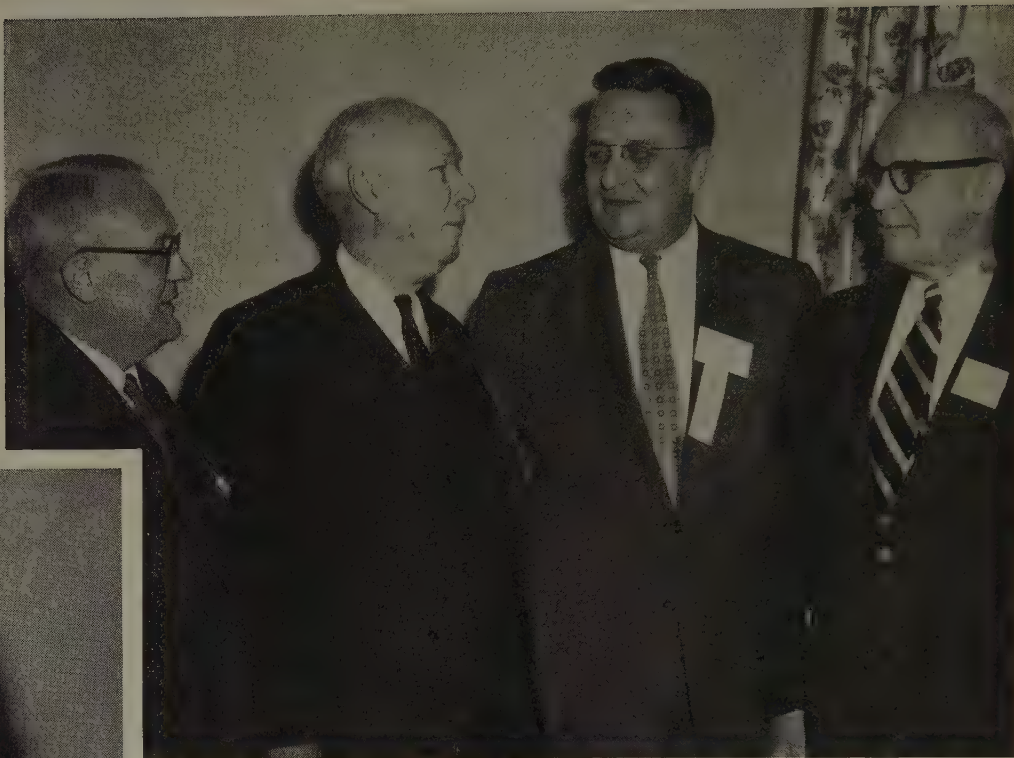
IRE PG on Electron Devices Annual Technical Meeting, Shoreham Hotel, Washington, D. C., Oct. 24–25

IRE-AIEE-ISA Eighth Annual Technical Conference on Electrical Techniques in Medicine and Biology, Washington, D. C., November

IRE Annual Electronic Conference, Towne House Hotel, Kansas City, Kansas, Nov. 3–4

IRE Southwestern Conference

Sponsored by Dallas-Fort Worth Section



(*Above*) The opening day speakers at the Dallas meeting are T. A. Hunter, Editor of the IRE Student Quarterly and President of Hunter Manufacturing Company, W. V. Houston, President of Rice Institute, J. D. Ryder, President of the IRE and Dean of the Michigan State College School of Engineering, and George W. Bailey, Executive Secretary of IRE.

(*Below*) John A. Green, Chairman of the Dallas-Fort Worth Section which sponsored the Southwestern Conference. Mr. Green is president of John A. Green Company.

(*Right*) Conference leaders are R. A. Arnett of the Houston Technical Laboratories, and James G. Flynn, Jr., Vice-President of Collins Radio Company. They served as Vice-Chairman and Chairman, respectively, of the Seventh Annual Meeting.

The Seventh Annual Southwestern IRE Conference and Electronics Show was held February 10 to 12 at the Baker Hotel in Dallas, Texas. The conference was sponsored by the Dallas-Fort Worth Section.

Special events included a reception for President John Ryder, an Executive Committee Meeting for Region Six, a ladies' program, a cocktail party and banquet, and a Directors meeting. John F. Jordan, IRE Fellow and Director of engineering and research for the Baldwin Piano Company, spoke at the banquet on "Musical Tone Color." Included in the special events were tours of seven plants in the Dallas area. At the Electronics Show there were exhibits by nearly eighty concerns.

Theme of the conference program was "Our Expanding Technology." The program included Airborne Electronics, Geophysics, Computers, Applied Electronics, Television, Automatic Control, Solid State Electronics, Microwaves, and Audio. Papers were presented by: Airborne Electronics—R. E. Lanier, B. L. Powell, B. H. Easter, E. H. Flath, Jr., and F. E. Schulte. Geophysics—M. A. Arthur, G. W. Fordham, G. C. Summers, and H. J. Jones. Computers—L. E. Heizer, H. M. Martinez, J. F. Forrester, F. S. Preston, and P. A. Dennis. Applied Electronics—K. B. Bennett, F. W. Tatum, D. F. Sellers, W. G. Redmond, and C. J. Schultz. Television—J. W. Wentworth, I. C. Abrahams, D. A. Peterson, and J. P. Gallagher. Automatic Control—L. B. Wadel, E. J. Kompass, H. A. Spuhler, J. M. Salzer, R. G. Brown, and A. R. Teasdale, Jr. Solid State Electronics—W. J. Pietenpol, J. W. Englund, K. E. Loofbourrow, W. A. Adcock, and C. P. Dotson. Microwaves—N. L. Pappas, J. R. Linciocome, V. Graziano, R. W. Haegele, and C. C. Campbell. Audio—W. Rudmose, J. D. Colvin, W. E. Stewart, and W. E. Seaman. Contributing to the success of the conference were: J. G. Flynn, Jr., *Chairman;* R. A. Arnett, *Vice-Chairman;* J. H. Honsy, *Secretary;* J. S. McNeely, *Treasurer;* T. A. Wright, Jr., *Technical Program;* Mark Shepherd, Jr., *Registration;* Thomas B. Moseley, *Inspection Tours;* James O. Weldon, *Banquet;* John Albano, *Housing;* Theil Sharpe, *Exhibits;* Mrs. D. H. Clewell, *Ladies' Program.*

Seventh Region Technical Conference Will Meet May 27–29

From April 27 to 29 the Phoenix Section will be host to the Seventh Region Technical Conference and Trade Show at the Hotel Westward Ho in Phoenix, Arizona.

The three days of technical sessions will feature thirty-five papers on Engineering Management, Semiconductors, Specialized Components, Special Measuring Techniques and Testing Equipment, Missile Design Considerations and Missile Equipment, and Telemetering Problems. These papers will present interpretive rather than theoretical material, emphasizing information which can be applied to design and development problems.

The manufacturers will provide a show featuring the latest developments in the field of electronics and plans have been made for a women's program. Social activities will include an informal registration get-together on April 26, a conference luncheon on April 27, and a western barbecue dinner and cocktails, on April 28. Especially for the women, arrangements have been made for a fashion show featuring creations by Western designers, and a tour of the Valley of the Sun with a luncheon in Scottsdale, "the West's most Western town." On Saturday, April 30, special arrangements may be made for visits to Nogales, Mexico, Boulder Dam, Grand Canyon, and local resorts.

IRE Manual of Standardization Now Available to Members

The IRE Manual of Standardization, which describes the procedure of standardization followed by Technical Committees, is now available to members. Copies may be obtained from the Office of the Technical Secretary at IRE Headquarters.

William Dubilier Receives Cooper Union Alumnus Award

William Dubilier, IRE Fellow and founder of the Cornell-Dubilier Electric Corporation, has received the Gano Dunn Medal for outstanding professional achievement by a Cooper Union alumnus. The annual award, given for the first time this year, was presented February 12 at the Founders Day Dinner in the Hotel Commodore, New York City.

William Dubilier

Mr. Dubilier received the award for his contributions to the development of high voltage condensers. Among his other awards are the Chevalier Cross of the Legion of Honor, Officer of the French Academy, Grand Medal of the Association des Ingenieurs-Docteurs de France.

Chicago to Be Host to National Telemetering Conference

The National Telemetering Conference, sponsored by the IRE, AIEE, IAS, and ISA, will meet May 18 to 20 at the Hotel Morrison in Chicago. The program will feature papers and exhibits in *Industrial Telemetering, Pickups and Transducers, Telemetering Components, Data Processing, Flight Testing, Multiplexing Techniques, Developments in Telemetry and Remote Control.*

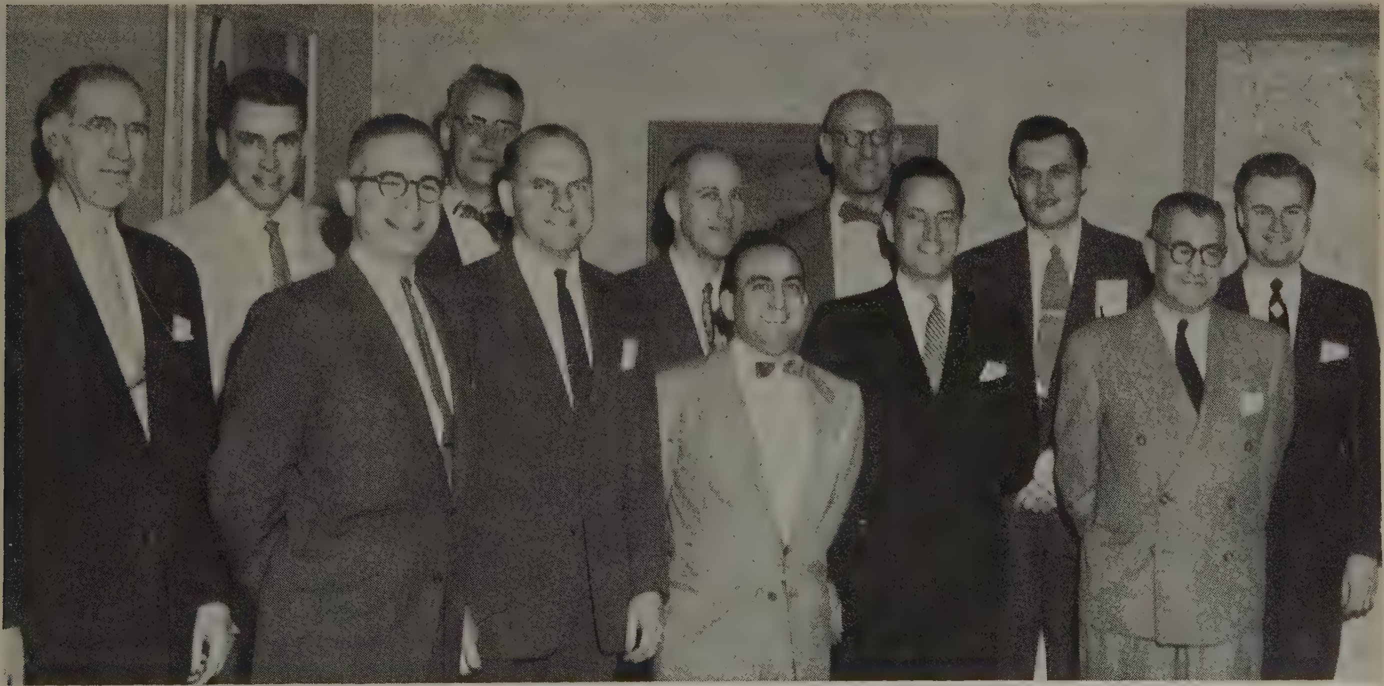
Hugh L. Dryden, Director of the National Advisory Committee for Aeronautics will speak to the conference on "Problems in Ultra High Speed Flight." Luncheon speaker will be W. A. Wildhack of the National Bureau of Standards.

Inquiries regarding exhibits should be addressed to G. Brittain, Armour Research Foundation, Chicago, Illinois. For further information concerning the program, write to C. H. Hoeppner, Stavid Engineering, Inc., Plainfield, New Jersey.

Syracuse Forms Three Chapters

On January 6 at the Syracuse Museum of Fine Arts three new professional group chapters were formed. These were the first chapters to be formed in the Syracuse Section and *pro tem* chairmen were selected to head each group. Donald E. Maxwell is Chairman of the Audio Chapter. Wilbur R. LePage of Syracuse University, heads the Circuit Theory Chapter, and C. Graydon Lloyd directs the Engineering Management Chapter.

Speakers on the program represented the various interests of the newly formed chapters. W. R. G. Baker, General Electric Vice-President and General Manager of the Electronics Division, was the first speaker. Dr. Baker gave a history of IRE professional groups, covering their initial conception and philosophy and their development up to the present. H. Brainard Fancher, General Electric General Manager of Germanium Products, reviewed the essential characteristics of a good manager. He defined the managerial function and explained how it was practically fulfilled. Norman Balabanian, Syracuse University, noted that the many branches of network theory arise from the application of various mathematical methods to network problems. The most used tool at present is complex function theory. Norman S. Cromwell, General Electric Radio and Television Department, discussed and demonstrated the application of low pass filters to prevent the energy in low frequency room and turntable vibrations from saturating and distorting the desired output of a high fidelity record player.



(Left to right) Past Chairman Richard Shea, Meeting Arrangement Coordinator; Speaker Norman Cromwell; Syracuse Section Chairman William Hall; Vice-Chairman Daniel Healy; Chairman Don Maxwell, Audio; Speaker H. Brainard Fancher; Speaker Norman Balabanian; Chairman Wilbur LePage, Circuit Theory; Chairman Graydon Lloyd, Engineering Management; Meetings and Papers Committee Chairman Don Arsem; Speaker Walter R. G. Baker, and the Secretary-Treasurer Major A. Johnson

Summer Courses in Nuclear Reactors and Automatic Control Offered by U of Michigan

An intensive course on Nuclear Reactors and Radiations in Industry will be presented August 15 to 26 by the University of Michigan. Tuition, covering fee for a printed set of course notes, will be $200 and the registration deadline will be June 1.

Sponsored by the Nuclear Engineering Committee of the College of Engineering, the course will be conducted by guest lecturers and staff members, including L. E. Brownell, H. J. Gomberg W. Kerr, H. A. Ohlgren and J. R. Sellars. Further details may be received from Prof. William Kerr, Department of Electrical Engineering, University of Michigan, Ann Arbor, Michigan.

Two intensive courses in Automatic Control will also be offered by the university. Course I is scheduled for June 13 to 18 and Course II is scheduled for June 20 to 22. Closing date for registration is April 15.

The courses are built around the principles and application of measurement, communication, and control. Course I will consist of the fundamentals in each of these fields and will include work in nonlinear systems. Course II will consider applications of the fundamentals to more advanced problems. More information may be obtained by writing to Prof. L. L. Rauch, Room 1521, East Engineering Building, University of Michigan, Ann Arbor, Michigan.

Technical Writers Will Meet

A two-day meeting of technical writers and editors will be held May 12 and 13 at the Statler Hotel in New York City. Ten papers will be presented by well-known representatives of industry, government, and education. The meeting will also discuss plans for a more formal organization of technical writers and editors.

Robert T. Hamlett of Sperry Gyroscope Company is Chairman of the group and Elsie Ray, Anaconda Copper Mining Company is Secretary.

Transistor Bibliography Ready

Through the courtesy of the Northwestern University Technological Institute, a comprehensive bibliography of transistors is now available. Reprints of the publication may be obtained without charge from A. R. Krull, Technological Institute Library, Northwestern University, Evanston, Illinois. Requests should designate "Transistors and Their Applications, A Bibliography, 1948–1953," by Alan R. Krull. IRE Trans. PGED, Vol. ED-1, No. 3, 1954, pp. 40–70.

Symposium on Modern Network Synthesis to Be Held in April

An international Symposium on Modern Network Synthesis will be held April 13 to 15 at the Engineering Societies Building in New York. The fifth in a series by the Microwave Research Institute, it is part of the celebration commemorating the 100 anniversary of the Polytechnic Institute of Brooklyn.

The program will consider advances in the synthesis of passive networks in the frequency and time domains. It will include improved methods for designing RLC transducers and advances in the design of sampling filters. Developments in active and non-reciprocal circuits, such as unconventional applications of transistors, will also be presented. A roundtable discussion is planned on the significance of new network synthesis techniques to the solution of design problems in industry.

The cooperation of the PG On Circuit Theory and the co-sponsorship of the Office of Naval Research, Air Force Office of Scientific Research, and Signal Corps permits the symposium to be held without admission charge or registration fee. Volume V of the MRI Symposia Series, "Proceedings of the Symposium on Modern Network Synthesis, II" will be published by October 1955, at five dollars per copy. Copies of the program, hotel accommodation information and registration forms are available from: Polytechnic Institute of Brooklyn, Microwave Research Institute, 55 Johnson Street, Brooklyn 1, New York.

Digital Machines for Nationwide Dialing to Be Discussed

The Boston Section and the Boston Chapter of the Professional Group on Electronic Computers will hold a joint meeting on April 21 to discuss "Digital Machines for Nationwide Dialing."

John Meszar, Director of Switching Systems Development at Bell Laboratories, will outline the progress of the new automatic long distance switching system developed at the laboratory.

Obituaries

Charles Jackson Pannill, IRE Fellow, former President of the Radiomarine Corporation of America, and of RCA Institutes, Incorporated died recently.

Mr. Pannill held the first Certificate of Skill in Radio Communications and the first radio operator's license issued by the United States Government. He retired in 1947 after nearly half a century in radio communications.

His career in communications began in 1898 when he enlisted in the Navy as a telegrapher during the Spanish-American War. After tours of duty at the Norfolk Navy Yard and Coast Signal Service, he applied his telegraphic training to wireless communications under Professor Reginald A. Fessenden. It was at Brant Rock, Massachusetts in 1906 that Professor Fessenden conducted the first transatlantic demonstration of the spoken word. Mr. Pannill later assisted Professor Fessenden in the first installation of radio equipment aboard a United States battleship, and in the inauguration of overland wireless communications between New York, Philadelphia and Washington, D. C.

He joined the Marconi Wireless Telegraph Company of America, predecessor of RCA, in 1912 and served for two years as Superintendent of the Southern Division. Re-entering the Navy in 1914, he assisted in the establishment of the Naval Communication System. He later became Assistant to the Director of Naval Communications, but resigned from the service in 1919.

During the following eight years, Mr. Pannill served as Vice-President and later President of the Independent Wireless Telegraph Company. In 1927, he was American delegate to the International Radio Conference. In 1928, he joined the Radiomarine Corporation of America, a service of RCA, as Vice-President and General Manager. He became Executive Vice-President in 1931, and was President from 1935 until his retirement in 1947. He served as President of RCA Institutes from 1932 until 1947.

Mr. Pannill received the Degree of Chevalier of the First Order of Leopold from the Belgian government for his work in international marine communications, and was awarded the Marconi Memorial Medal of Achievement by the Veteran Wireless Operators Association. He was a member of the Society of Naval Architects and Marine Engineers, the Cosmos Club, the New York Maritime Exchange, and the Board of Managers of Seaman's House of New York City. He was also a former Governor of the Propeller Club of New York.

Professional Group News

Three New Chapters Approved

At a meeting on February 1, the Executive Committee approved petitions for the formation of the following chapters: PG on Audio, San Antonio Chapter; PG on Electronic Computers, Baltimore Chapter; PG on Information Theory, White Sands Proving Ground Chapter (El Paso Section).

Technical Committee Notes

The **Antennas and Waveguides** Committee met at IRE Headquarters on January 12. Chairman P. H. Smith presided at the meeting. The possibility of standardizing impedance or reflection charts was discussed.

The committee discussed its published *Standards* which are in need of review (*Standards on Antennas, Modulation Systems, and Transmitters: Definitions of Terms, 1948* and *Standards on Antennas: Methods of Testing, 1948*). It was announced that preparation of new definitions had been assigned to the West Coast Subcommittee and that H. Jasik's Subcommittee was preparing *Standards on Methods of Testing Waveguide Components*.

This committee met again on February 9 to discuss conflicts in the proposed *Definitions for Waveguide Components* with definitions approved by ASA Committee C42.

The **Facsimile** Committee met at the Times Annex in New York on January 7 with Vice-Chairman A. G. Cooley presiding and on February 11 with Chairman H. F. Burkhard presiding. The Committee's proposed definitions were discussed, and plans were made for reproducing the Facsimile Test Chart prepared by the committee.

The **Feedback Control Systems** Committee met at the MIT Faculty Club in Cambridge on January 11, with J. E. Ward presiding. The committee reviewed the pro-

posed *Standards on Graphical and Letter Symbols for Feedback Control Systems* and the proposed *Standards on Terminology for Feedback Control Systems*. The formation of a new subcommittee on Measurements was discussed. Terms prepared by G. Biernson and W. B. Williams were referred to the Definitions Subcommittee.

The **Radio Transmitters** Committee met on January 12 at IRE Headquarters with P. J. Herbst presiding. The committee formulated new terms in the field of spurious transmitter output. Three subcommittee chairmen made reports: Harold Goldberg reported that the proposed *Methods of Measurement of Pulse Quantities* was being revised and would be submitted to the main committee in two months. T. M. Gluyas, Jr. stated that work would be resumed on the proposed *Standards on Monochrome Television Transmitters*. Chairman B. Sheffield of Subcommittee 15.2 agreed to review with the subcommittee the suggestions of the main committee for the proposed *Standards on Methods of Testing Radio-Telegraph Transmitters (Below 50 MC)*.

The **Electron Devices** Committee met on January 21 at IRE Headquarters with Chairman W. J. Dodds presiding. The Subcommittee on Cathode-Ray and Television Tubes announced that they were beginning activity on methods of testing. The Subcommittee on Gas Tubes has prepared a list of Gas Tube Definitions. The Subcommittee on Camera Tubes, Phototubes, and Storage Tubes in Which Photoemission Is Essential reported that Camera Tube Definitions will soon be ready for consideration by the committee and gave suggestions for liaison of the Electron Devices Committee and the new committee on nuclear science, soon to be formed. The Subcommittee on High-Vacuum Microwave Tubes reported that three task groups (Cold Test, Oscillators, and Amplifiers) were working on standards. The Physical Electronics Subcommittee reported that a review of definitions is almost completed. R. M. Ryder, Chairman of the Solid State Devices Subcommittee stated that proposed *Methods of Testing Transistors* are ready for submittal to the Standards Committee. He also reported on proposed standards in the following fields now in preparation in this subcommittee and its task groups: Large Signal Test, Point Contact Transistors; Letter Symbols for Transistor Qualities; Large Signal Tests for Junction Transistors; Single Tests on Power Transistors; Definitions of Hybrid Parameters. Recommendations for chairman of a Task Force on Ferroelectric and Ferromagnetic Devices were requested. Two subcommittees will make recommendations for assignment of work on temperature-sensitive resistors. It was noted that both the Tube Conference and the Semiconductor Conference were fully organized for 1955.

The **Measurements and Instrumentation** Committee met on January 31 at IRE Headquarters with P. S. Christaldi presiding. The following subcommittee reports were given: C. D. Owens (Magnetic Measurements Subcommittee) reported that the problem of testing ferrite core antennas for broadcast receivers would be considered by this subcommittee. The written report of A. P. G. Peterson of the Subcommittee on Audio-Frequency Measurements stated that revision of proposed *Standards on Nonlinear Distortion* was being continued in co-operation with two other IRE subcommittees. The Subcommittee on Video-Frequency Measurements reported that the work on angle and delay measurements should be completed by June, 1955. Dr. Showers, Chairman of the Interference Measurements Subcommittee, reported that his subcommittee was co-operating in the work of the Ad Hoc Committee on Spurious Radiation (Standards Committee). Definitions of terms compiled by the Subcommittee on Oscillography were described as nearly complete by the chairman, M. J. Ackerman. This subcommittee will also study measurements made with cathode-ray instruments. After hearing the subcommittee reports, the committee discussed the *Compilation of References to Methods of Measurement* which it plans to prepare.

The **Audio Techniques** Committee met at IRE Headquarters on February 9 with Chairman D. E. Maxwell presiding. L. D. Runkle, Chairman of the Definitions Subcommittee, reported on the action of his group on the proposed definitions. A report of Chairman R. C. Moody of the West Coast Subcommittee was read, describing the work on the proposed *Standard on Intermodulation Distortion*. The committee reviewed the proposed *Standards on Methods of Measurement of Gain, Loss, Amplification, Attenuation and Frequency Response* which is nearing completion.

Books

Electronics by A. T. Starr

Published (1954) by Pittman Publishing Corp., 2 West 45th St., New York City. 388 pages+7 page index+viii pages. 352 figures. $8\frac{3}{4}\times 5\frac{3}{8}$. $7.50.

This book was written by Dr. Starr especially to cover the requirements of the electronics examination for the degree of Bachelor of Science in Engineering at the University of London. It makes no pretense at being a textbook. Within its scope it is an excellent reference volume; it should be a great help to engineers reviewing (not studying for the first time) the field of electronics in preparation for State Licensing or university doctoral examinations.

The emphasis of the book is on electronic circuitry rather than on the physics of electron tubes. Probably no two authors would agree on just what to include in such a book, but to this reviewer it seems that Dr. Starr has made a good selection. His presentation of topics is both clear and concise. At the end of each chapter there is a group of problems taken from recent London University examinations, and at the end of the book there is a set of answers to a few of these problems.

The six chapter titles are: "Physical Fundamentals"; "Valves"; "Rectification"; "Circuit Theory"; "Amplifiers, Oscillators and Detectors"; and "Electronic Applications." There are, in addition, seven appendixes covering various mathematical topics.

This reviewer believes that there should be at least a few references to other literature on the various topics discussed, but, other than that, feels that Dr. Starr had done an excellent job.

F. T. McNamara
Dept. Electrical Engineering
Yale University
New Haven, Connecticut

Television, Second Edition by V. K. Zworykin and G. A. Morton

Published (1954) by John Wiley and Sons, Inc., 440 Fourth Ave., New York 16, N. Y. 1020 pages+xv pages+17 page index. Illustrated. $6\frac{1}{4}\times 9\frac{1}{16}$. $17.50.

What can be said in a love song that hasn't been said before? The second edition of this classic book is a complete reworking of the field and is even more of a gold mine than the first edition. Despite compression and omission of some of the topics which are better known now, the authors have been forced to expand the size of the book by approximately sixty per cent. Color fundamentals and practical color and industrial television systems account for about half of the expansion in four new chapters. The rest is just to take care of discussions of the new techniques evolved during the last fourteen years.

Every chapter has been revised and many completely rewritten.

The material covered ranges from the physics of electron emission and the fundamentals of color vision to discussions of the uses of television receivers in home management and interplanetary travel. The greatest stress is laid on those topics which are peculiar to television.

The treatment is thorough and restrainedly technical; mathematics is used where necessary. The prose is clear and readable. The book is well illustrated both with line drawings and half-tones. A knowledge of basic radio and circuit theory is assumed.

This is a must for every engineer interested in television.

Knox McIlwain
Hazeltine Electronics Corporation
Little Neck, New York

Review Credit Correction Noted

In the February issue H. J. Carlin was incorrectly credited with reviewing *Magnetic Amplifier Circuits* by W. A. Geyger. E. J. Smith, Polytechnic Institute of Brooklyn, should have been listed as the reviewer.

Electrical Transients by L. A. Ware and G. R. Towne

Published (1954) by Macmillan Co., 60 Fifth Ave., N. Y., N. Y. 219 pages+2 page index+xi pages. Illustrated. $5\frac{5}{8}\times8\frac{1}{4}$. $4.75.

This book is intended as a text for undergraduate electrical engineering students at the junior or senior level. It is primarily an introduction to the Laplace transform with applications to the solution of the differential equations of simple electric circuits. The position of the authors, that the teaching of the Laplace transform to undergraduate students is not only feasible but highly desirable, seems well taken. The limited aspects of the subject which are dealt with in this book require no mathematics beyond that normally given in undergraduate studies.

The title is perhaps inappropriate since there is very little discussion of transient phenomena as such. The direct Laplace transform is presented in Chapter Two and the remainder of the book is devoted to applications. The major emphasis is on the mechanics of the solution of circuit problems by Laplace transform. As an introduction to the transform method *Electrical Transients* is fairly good.

Unfortunately, the preoccupation with the manipulations required to solve various differential equations results in a complete neglect of the conceptual advantages afforded by the Laplace transform. The use of the impedance or admittance concept in obtaining transform relationships is ignored except for a footnote. Instead, the authors write down the differential equations for each problem and then transform them term by term. The link between the behavior of linear networks in the time and frequency domains, which is perhaps more important than any other single aspect of the Laplace transform, is also completely ignored. The treatment of initial conditions is not, as is strongly implied, the major advantage of the Laplace transform.

Many examples are worked out in the book and additional problems are given at the end of the chapters. The long involved treatment of the shunt-peaked video amplifier given in Chapter Nine seems of questionable value, but in general the problems are well chosen and should be helpful to the student. However, in spite of some good features and a worthwhile objective, the over-all treatment is not as good as it might be and leaves much to be desired.

Leonard A. Goldstone
Polytechnic Inst. of Brooklyn
Brooklyn, N. Y.

Electromagnetic Theory by V. C. A. Ferraro

Published (1954) by John de Graff, Inc., 64 West 23 St., N. Y. 10, N. Y. 550 pages+viii pages+5 page index. 161 figures. $8\frac{3}{4}\times5\frac{3}{4}$. $7.00.

This book follows the historical approach set by Maxwell in his classic treatise, an approach which has been followed by many writers in electromagnetic theory. Ferraro's text differs from older treatises of this school (e.g. J. H. Jeans, *Electricity and Magnetism*, Cambridge 5th edition, 1933) in that vector notation is used, including an introductory chapter on vector analysis, and the book is modern in language and notation. It differs from other modern books of similar outline (e.g. W. R. Smythe, *Static and Dynamic Electricity*, McGraw-Hill, second edition, 1950) in that classical cgs units are used rather than the rational mks system; there is slightly more emphasis on the mathematical proofs and somewhat less emphasis on specific applications. However, examples are worked out at the end of each chapter and there are extensive listings of problems, many taken from the Cambridge and University of London examinations.

The author states that the book is intended primarily for mathematicians and only secondarily for physicists and engineers. Thus there are several valuable proofs of uniqueness and existence for the stationary field. The major part of the text has, however, to do with the physical laws and their interpretation, and all of the book can be followed readily by graduates or advanced undergraduates in science and engineering.

Magnetic fields are introduced through the concept of magnetic charges. This approach has the advantage of stressing the similarities between electric and magnetic fields, but the disadvantage of masking the differences, and of requiring the difficult proof of equivalence between current flow and a magnetic shell. The author claims novelty for his proof of this point, and the proof seems direct.

The writing is concise and clear. The major fault is one which seems to come naturally to texts following the historical approach—treatment of the time-varying electromagnetic field is relegated to a secondary position out of keeping with its present importance. Less than one-fifth of this text is devoted to the time-varying field. Applications are seldom mentioned, and even the proofs of existence uniqueness, and convergence, which might be expected in a text for mathematics, are omitted.

J. R. Whinnery
University of California
Berkeley, California

Feedback Control Systems by Gilbert Howard Fett

Published (1954) by Prentice-Hall Inc., 70 Fifth Ave., N. Y., N. Y. 351 pages+5 page index+ix pages +4 page index+4 page appendix. Illustrated. $8\frac{1}{4}\times6\frac{1}{4}$. $10.00.

This book is a text covering the theory and analysis of feedback control systems. The presentation is pitched at a level suitable for senior undergraduate or graduate students or for practicing engineers who desire an introductory grounding in the field. The coverage of material ranges from a brief presentation of the components of feedback systems, time domain analysis of linear closed loop systems, a substantial discussion of frequency domain methods of analysis, to a chapter on non-linear systems.

The material is presented in a manner which reflects the fact that the author has had teaching experience. Explanations are clear and the order of presentation logical. On the other hand, there is a rather heavy emphasis on the more academic discussions of stability and stability diagrams at the expense of practical problems encountered in synthesis. For instance, considerable space is devoted to the Nyquist diagram and to modified transfer loci which result from the mapping of paths other than the imaginary axis, such as a displaced imaginary axis, and of straight lines at a fixed angle with respect to the imaginary axis. While interesting from an academic viewpoint, these studies are not too important in practice. The low accuracy with which system constants are known and the difficulty of correlating these loci with time domain response do not always warrant such detailed and precise analyses of modified transfer loci.

The book would have profited from inclusion of more material on system design of feedback control systems. A unified analysis of the methods of compensation and their effect on over-all performance and a discussion of the practical advantages of one form or another is missed. In the treatment of multiple loop systems, techniques for the reduction of the system to an equivalent single loop system for study and design is not pointed out. Also the inverse (M^{-1}) plane, a powerful yet simple approach to the design of feedback systems with other than unity or proportional feedback, is not adequately exploited.

Despite some differences in viewpoint, this reviewer would like to reemphasize that the text is a careful and technically correct work and that a reader would benefit by studying it carefully. The book contains a comprehensive bibliography and a set of practice problems at the end of each chapter so that the reader is able to extend and apply some of the concepts developed in the text. Some of the more practical aspects of design and synthesis can be supplemented by use of other sources.

This text is well recommended for those engineers or students who wish to be introduced to the underlying theory of feedback control systems.

John R. Ragazzini
Columbia University
New York, N. Y.

Recent Books

Alsberg, Harold, Ed., *TV Field Service Manual with Tube Locations: Volume Three.* John F. Ryder Publisher, Inc., 480 Canal Street, New York 13, N. Y. $2.10.

Courant, R. and Hilbert, D., *Methods of Mathematical Physics: Volume One.* Interscience Publishers, Inc., 250 Fifth Ave., New York 1, N. Y. $9.50.

Gray, Truman S., *Applied Electronics.* John Wiley and Sons, Inc., 440 Fifth Ave., New York 15, N. Y. $9.00.

La Joy, Millard H., *Industrial Automatic Controls.* Prentice-Hall Inc., 70 Fifth Ave., New York 11, N. Y. $6.65.

MacLanachan, W., Ed., *Television and Radar Encyclopaedia.* Pitman Publishing Corp., 2 West 45 Street, New York, N. Y. $6.00.

Noll, Edward M., *Television for Radiomen.* Macmillan Co., 60 Fifth Ave., New York 11, N. Y. $10.00.

Snitzer, Milton S., *TV Manufacturers' Receiver Trouble Cures: Volume Six.* John F. Ryder Publisher, Inc., 480 Canal Street, New York 13, N. Y. $2.10.

Zbar, Paul B., and Schildkraut, Sidney, *Advanced Television Servicing Techniques.* John F. Rider Publisher, Inc., 480 Canal Street, New York 13, N. Y. $3.60.

THE 1955 NATIONAL CONFERENCE ON AERONAUTICAL ELECTRONICS

Sponsored by the Dayton Section and
PG on Aeronautical and Navigational Electronics
Dayton Ohio, May 9–11

Monday Morning

Semiconductors I—Transistors and Rectifiers

Engineers Club, Auditorium

"Medium Powered, Hermetically Sealed, Silicon Rectifiers for High Temperature Applications," A. Bergson and W. G. Mitchell, Raytheon Mfg. Co.
"Semiconductor Power Rectifiers," J. W. Thornhill, Texas Instruments, Inc.
"Some Practical Considerations Concerning the Limiting Operating Voltages of Junction Transistors," W. E. Sheehan, Raytheon Mfg. Co.
"Transistor Pulse Characteristics," E. A. Hoskinson, North American Aviation, Inc.
"Silicon Power Transistors and their Applications," J. W. Lacy and P. D. Davis, Jr., Texas Instruments, Inc.

Antennas and Propagation I

Engineers Club, Italian Room

"Investigation of the Electrical Characteristics of Low Frequency Transmitting Antenna Towers by Scale Model Measurements," Sidney Rosenberg and Paul Wilson, USAF Rome Air Development Center.
"Aircraft Antenna System Lightning Protection," R. F. Huber, Joslyn Mfg. Co., M. M. Newman and J. D. Robb, Lightning & Transients Research Inst.
"An Evaluation of Liaison Antennas for the Boeing Jet Transport," O. C. Boileau, Jr., Boeing Airplane Co.
"Helicopter Antenna Design Considerations," A. R. Ellis, Stanford Research Institute.
"The Antenna Crossover Problem in Conical Scan Radar," M. S. Wheeler, Westinghouse Electric Corp.
"High Speed Sequential Lobing Antenna for Tracking Radar," J. T. McDonough, Westinghouse Electric Corp.

Management I—Engineering and Production

Biltmore Hotel, Main Ballroom

"Management of a Study Program," N. V. Petrou and J. E. Darr, Westinghouse Electric Corp.
"The Role of Electronics Research in Systems Engineering," Sidney Wald, The Glenn L. Martin Co.
"Management and Production of Airborne Electronics in the Event of Atomic War," A. S. Brown, Stanford Research Inst.
"A New Packaging Design Well Suited to Automation," D. H. Westwood, RCA.
"An Approach to the Packaging of Subminiature Electronic Equipment," A. H. Stoney, Sylvania Electric Products, Inc.
"Miniaturization and Unitization in Equipment Design," S. M. Stuhlbarg, Crosley Div., AVCO Mfg. Co.

Electronic Components I

Biltmore Hotel, English Room

"Design of Airborne Power Transformers from a Heat Transfer and Weight Point of View Using Forced Air Cooling and Metal Tape Windings," A. B. Cicero, Sylvania Electric Products, Inc.
"Airborne High Temperature Transformer and Reactor Components," A. Lucic, North American Aviation, Inc.
"Audio Frequency Selective Tunable Relay," Gerald Zomber, Avion Instrument Corp.
"The Model 307 Photo-Electric DC Chopper," F. H. Davis, Avion Instrum. Corp.
"Practical Design Criteria for High Order Mode Cavities," Amasa Pratt, Kearfott Co., Inc.

Monday Afternoon

Semiconductors II—Circuits

Engineers Club, Auditorium

"Microwave Video Detection Characteristics of Crystals," R. E. Henning, Sperry Gyroscope Co.
"Characteristics and Circuit Design for High Power Transistors," H. T. Mooers, Minneapolis-Honeywell Regulator Co.
"Transistor DC-DC Converters," D. A. Paynter, General Electric Co.
"Transistorized Time Encoder," J. C. Groce, Federal Telecommunication Labs., Inc.
"A Silicon Transistor Resolver Amplifier," W. W. Wells, North American Aviation, Inc.
"Transistor Application in a 2 to 8 MC Communications Receiver," H. J. Woll, RCA.

Antennas and Propagation II

Engineers Club, Italian Room

"Loop Antennas," Phyllis A. Kennedy and Thaddeus Kaliszewski, Harvard University.
"Evaluation of Structural Dielectrics for Use in Flush Type Cap Antennas," Bruce M. Sifford and Henry J. Sang, Stanford Research Inst.
"VSWR Circle Transformations," David A. Cope, Glenn L. Martin Co.
"Obtaining a Uniform Field in the Diffraction Zone of a Large Aperture," J. O. Stenoien, Boeing Airplane Co.
"Absolute Backscattering Measurements Employing the Synchrodyne Principle, Hybrid-T, and Image Plane in the K-Band," Capt. L. A. Yarbrough, USAF Institute of Technology.
"Characteristics of Meteor Bursts on 15 MC Over a 608 KM Path," H. T. Castillo, Dayton, Ohio.

Reliability

Biltmore Hotel, Main Ballroom

"Measuring, Assessing and Predicting Equipment Reliability," C. M. Ryerson, RCA.
"System Function or Information Flow as a Measure of Reliability," A. Kohlenberg, Melpar, Inc.
"Airborne Radar Reliability," A. M. Levine and A. J. Finocchi, Federal Telecommunication Lab.
"Airborne Radar Reliability," L. A. Mayberry, Motorola, Inc.
"Reliability in Complex Airborne Electronic Equipments," G. H. Scheer, USAF Wright Air Development Center.
"Field Support of Complex Airborne Electronic Equipment," H. W. Brown, Jr., RCA.

Measurement and Test I

Biltmore Hotel, English Room

"Characteristics of X-Band Radar Test Set," Murray Kaye, Sperry Gyroscope Co.
"A Calorimeter for Microwave Low Level Power Measurements," L. D. Strom, Texas Instruments, Inc.
"Improvements in Calorimetric Wattmeters and Water Loads," Samuel Freedman, Chemalloy Electronics Corp.
"Design Considerations for a New Type of Dummy Load," D. Self, Sperry Gyroscope Co.
"Recent Developments on the National Bureau of Standards Microwave Refractometer," M. C. Thompson, Jr., National Bureau of Standards.
"A Method of Wavelength Measurement for the Microwave and Millimeter Wave Regions," W. W. Balwanz, M. B. Rapport, and E. W. Ward, USN Naval Research Laboratory.

Tuesday Morning

Ferromagnetics and Plastics

Engineers Club, Auditorium

"Bimag Applications in Airborne Control Systems," I. L. Auerback, Burroughs Corp.
"A New Passive Magnetic Binary for Digital Applications," J. R. Horsch, General Electric Co.
"Ferrite Duplexers for Microwave Radar Applications," T. N. Anderson, Airtron, Inc.
"Plastics Material," J. H. DuBois, Mycalex Corp. of America.

"A New Class of Artificial Dielectrics for Microwave Applications," W. O. Puro, H. T. Ward, Jr., and D. M. Bowie, Melpar, Inc.

Human Engineering

Engineers Club, Italian Room

"A Miniature Airborne Pictorial Plotter," S. Romano, Avion Instrument Corp.
"A Preliminary Study of Operational Advantages of Pictorial Navigation Displays," F. S. McKnight, CAA Technical Development & Evaluation Center.
"Problems of Simulations with Human Subjects," M. Goetz, Westinghouse Electric Corp.
"Development of a Pilot Analog for the Single-Degree-of-Freedom Case," R. J. Mead and N. Diamantides, Goodyear Aircraft Corp.
"Some Human Engineering Problems in Fly by Wire Techniques," Arthur Kahn, Westinghouse Electric Corp.
"Human Engineering Analysis of Flight Director Systems," N. J. Cafarelli, Stavid Engineering, Inc.

Computers

Biltmore Hotel, Main Ballroom

"Gain Compensation for Airborne Analogue Computers," T. G. Nichols, Westinghouse Electric Corp.
"An Analogue Surface Function Generator," J. J. Earshen, Cornell Aeronautical Lab., Inc.
"Comparative Advantages of Airborne Digital Computers," D. L. Nettleton, RCA.
"Analysis of Systems Containing Digital Computers," E. Arthurs, RCA.
"The Flying Spot Scanner as a Digital Data Read Out Device," C. E. Jones, Federal Telecommunication Labs., Inc.

Servomechanisms

Biltmore Hotel, English Room

"Gain Equalization of Linear Servomechanisms which Solve Non-Linear Equations," G. E. Adams, Farnsworth Electronics Co.
"Feedback Control Systems Using Sampled Data," L. E. Mertens, RCA.
"Some Loading Effects on Servomechanism Performance," George Axelby, Westinghouse Electric Corp.
"Non-Linear Boost System Flow Characteristics and its Effect upon Autopilot Performance," A. M. Fuchs and F. J. Huddleston, Westinghouse Electric Corp.

Tuesday Afternoon

Forum: The Weapons Systems Concept and How It Affects Aeronautical Electronics

Engineers Club, Auditorium

Radio Interference

Engineers Club, Italian Room

"Low-Impedance Gaskets for Radio-Frequency Applications," Verne Pulsifer and A. J. Hoehn, Armour Foundation.
"Measurement of Interference Fields about Aircraft," J. R. Stahmann, Lightning and Transients Research Institute.
"Radio Interference Control in Aircraft," A. L. Albin and J. E. McManus, Armour Research Foundation.
"A Study of Interference between Messages from Independent Multiple Sources on a Single Channel," Bobby Buchanan, USAF Cambridge Research Center.
"Interference Blankers," R. O. Engels, USAF Rome Air Development Center.
"Study of Noise Reduction by Feedback in Ultra-High Frequency Amplifiers," A. B. Glenn, RCA.

Environmental Conditions

Biltmore Hotel, English Room

"A Comparison of the Thermal Efficiencies of Subminiature Tube Shields Using a New Method of Measurement," L. C. Calhoun, Westinghouse Electric Corp.
"Relationship between Heat and Temperature or How Is a Dissipation in Watts Related to the Temperature of Parts," A. S. Gutman, Sylvania Electric Products, Inc.
"General Design Aspects for Cooling Electronic Equipment," M. Mark, Raytheon Mfg. Co.
"Reliable Tube Bulb Temperatures and Plate Operating Ratings," E. S. Mockus, Raytheon Mfg. Co.

Wednesday Morning

Electron Tubes I

Engineers Club, Auditorium

"Some Results of a Comprehensive Program to Improve Tube Reliability, Arthur Kohlenberg," Melpar, Inc.
"Developmental Low Noise TW Tubes for L-, S-, and C-Band," P. R. Wakefield and A. G. Hogg, RCA.
"A Developmental High Power Tunable X-Band Pulse Magnetron for Airborne Applications," W. F. Beltz, RCA.
"A High Power X-Band Klystron," R. A. LaPlante, Philips Laboratories.
"Casting Waveguides Complete with Flanges by the Shell Molding Process," Samuel Freedman, Chemalloy Electronics Corp.

Equipment I

Engineers Club, Italian Room

"A Precise 60 CPS 6.5 KVA Power Source," F. A. Kahl, Bendix Radio.
"Ultra-Linear, Wide Range 400-Cycle to D-C Converter," Darwin Krucoff, Melpar, Inc.
"An Airborne Radio Sextant," R. M. Ringoen, Collins Radio Co.
"AVQ-10 Commercial Airlines Weather Radar," C. J. Monroe and Aubrey W Vose, RCA.
"Precision Ranging with a Pulsed Optical Radar," Leonard Geller and John Lawton, Cornell Aeronautical Laboratory, Inc.
"Pod-Mounted Electronic Equipment has Advantages," H. A. Brelsford, RCA.

Navigation I

Biltmore Hotel, Main Ballroom

"An All Weather Radio Sextant," D. O. McCoy, Collins Radio Co.
"Model Measurements of Rotor Modulation for VOR Antennas," W. E. Barrick, Electronics Research, Inc.
"Measurement of TACAN and VOR Bearing Errors," D. T. Latimer, Jr., USN Naval Air Test Center.
"Recent Developments in Distance Measuring Equipment (DME)," R. C. Borden, Civil Aeronautics Administration TDEC.
"Radio Beam Coupler System," Herbert Hecht and G. F. Jude, Sperry Gyroscope Co.
"The RHO in Navarho," Raymond Alexander, American Machine & Foundry Co.

Measurement and Test II

Biltmore Hotel, English Room

"Propeller Blade Angle—and Deflection-Measurement," J. C. Camm, Electronics Corp. of America.
"A Pulse System of Strain Recording," P. L. Toback, Armour Research Foundation.
"A Versatile 200 Channel Recorder for Static Stress Analysis," T. C. Fletcher, Beckman Instruments, Inc.
"A Miniaturized Telemetering System Resulting from Modern Design Techniques," I. P. Magasiny, Raymond Rosen Engineering Products, Inc.
"Flight Testing an Airborne Magnetic Tape Data Recorder," J. J. Dover, USAF Flight Test Center.
"Signal Generator," Norman Greenberg, Avion Instrument Corp.

Wednesday Afternoon

Electron Tubes II

Engineers Club, Auditorium

"Magnetron Beam Switching Tube," Hilary Moss, Burroughs Corp.
"Recent Developments in the Raytheon Recording Tube," R. C. Hergenrother, A. L. Luftman, and C. S. Sawyer, Raytheon Mfg. Co.
"Stacked Ceramic Tubes," H. E. Sorg, Eitel-McCullough, Inc.
"Status of Stacked Tube Development," W. R. Wheeler, Sylvania Electric Products, Inc.
"Ceramic Techniques and Parts Fabrication for Vacuum Tube Applications," T. S. Stanislaw, Sylvania Electric Products, Inc.

Information Theory

Engineers Club, Italian Room

"Z Transform for Multiple Sampled Systems," N. T. Simopoulos, U. of Dayton.
"Modern Network Theory Design of Crystal Filters for Communications and Navigation," M. Dishal, Federal Telecommunication Labs., Inc.
"Phase Detector for Pulsed I-F Signals," O. E. Linderman, General Electric Co.
"The Philosophy of Design of Data-Processing Systems," R. L. Whittle, Federal Telecommunication Labs., Inc.

"A 30-Target Electronic Radar Simulator: Its Application to Human Engineering and Systems Research," Lowell Schipper, Ohio State University.
"A Multiple Target Radar Simulator," Sidney Wald, Glenn L. Martin Co.

Navigation II

Biltmore Hotel, Main Ballroom

"The Magnetic Drum as an Aid for Air Traffic Control and Weather Reporting," G. E. Fenimore, CAA Technical Development & Evaluation Center.
"A Novel Holding Pattern for Inbound Airplanes," C. E. Young, Cornell Aeronautical Laboratory, Inc.
"Analytic Approach to the General Air Traffic Control Problem," L. J. Fogel and N. J. Cafarelli, Stavid Engineering, Inc.
"Evaluation of the Rho/Theta Transponder System for Air Traffic Control," D. S. Crippen and J. E. Herrmann, CAA Technical Devt. & Eval. Ctr.
"An Investigation of Ilas Beam Characteristics and Aircraft Tracks," Abe Tatz, Airborne Instruments Lab., and Capt. C. P. Thomas Wright Air Development Center.
"A Broad Band Blue Lighting System for Radar Approach Control Centers," C. L. Kraft and P. M. Fitts, Ohio State University and Arthur Perong, USAF Wright Air Development Center.

Circuits

Biltmore Hotel, English Room

"A High Stability RF System for DME Interrogators," M. Feller, Federal Telecommunication Labs., Inc.
"8.5–15 CM Plate Pulsed Reentrant Oscillator Circuits," W. E. Babcock, RCA.
"TEM Mode Microwave Filters," D. V. Geppert and R. H. Koontz, Sylvania Electric Products, Inc.
"A Wideband Low-Noise Amplifier for Millimicrosecond Pulses," Harry Kihn, RCA.
"A Precision Omnibearing Selector for the Test and Adjustment of VOR Receivers," R. L. Olson, Collins Radio Co.

1955 IRE CONVENTION RECORD

All available papers presented at the 1955 IRE National Convention will appear in the IRE Convention Record to be published in June. The Convention Record will be issued in ten Parts, with each Part devoted to one general subject. The papers for each session are listed on pages 349–377 of the March issue.

Instructions on Ordering

1. If you are a member of a Professional Group and have paid the group assessment by April 30, you will automatically receive, free of charge, that Part of the Convention Record pertaining to the field of interest of your group, as indicated in the chart below.

2. If you are not a member of an IRE Professional Group, Convention Record, Parts may be purchased at the prices listed in the chart below. Orders must be accompanied by remittance, and to assure prompt delivery, should be sent immediately to The Institute of Radio Engineers, 1 East 79 Street, New York 21, N. Y.

Convention Record

Part	Title	Free To Paid Members of Following Professional Groups	Prices for Members (M) College and Libraries (L) Non-Members (NM)		
			M	L	NM
1	Antennas & Propagation **Sessions: 2, 10, 33, 40**	Antennas & Propagation	$1.00	$2.40	$3.00
2	Circuit Theory **Sessions: 7, 32, 39**	Circuit Theory	1.00	2.40	3.00
3	Electron Devices and Components Parts **Sessions: 16, 23, 43, 44, 51, 52**	Electron Devices Component Parts	1.50	3.60	4.50
4	Computers, Information Theory, Automatic Control **Sessions: 8, 14, 24, 27, 35, 42, 48, 53**	Electronic Computers Information Theory Automatic Control	2.25	5.40	6.75
5	Aeronautical and Navigational Electronics **Sessions: 11, 19, 55**	Aeronautical & Navigational Electronics	1.00	2.40	3.00
6	Management, Quality Control, and Production **Sessions: 18, 29, 37, 46, 50**	Engineering Management Reliability and Quality Control Production Techniques	1.50	3.60	4.50
7	Transmitters, Receivers, and Audio **Sessions: 12, 13, 20, 21, 25, 31, 38**	Broadcast Transmission Systems Broadcast & Television Receivers Audio	2.50	6.00	7.50
8	Communications and Microwave **Sessions: 3, 4, 28, 36, 47, 54**	Communications Systems Vehicular Communications Microwave Theory and Techniques	2.00	4.80	6.00
9	Ultrasonics, Medical and Industrial Electronics **Sessions: 5, 26, 34, 41, 49**	Ultrasonics Engineering Medical Electronics Industrial Electronics	1.50	3.60	4.50
10	Instrumentation, Telemetry and Nuclear Science **Sessions: 1, 6, 9, 15, 17, 22, 30, 45**	Instrumentation Telemetry and Remote Control Nuclear Science	2.50	6.00	7.50
	Complete Convention Record (All Ten Parts)		$16.75	$40.20	$50.25

NATIONAL TELEMETERING CONFERENCE

SPONSORED JOINTLY BY IRE, AIEE, IAS, AND ISA

CHICAGO, ILLINOIS, MAY 18–20

Wednesday Morning

COMPONENTS I

INDUSTRIAL TELEMETERING

Chairman, K. C. Black

"A New High-Speed Telemeter Transmitter for dc Measurements," R. M. Stuart, General Electric.

"A New Electronic Telemetering Transmitter for Pilot Wire Applications," T. Barabutes, Westinghouse Electric & Manufacturing.

"An Incremental Remote Position Control System," Jonathan Mass, Kiryat Motzkin, P.O. Box 1, Haifa, Israel.

"A New Time Interval Telemeter System," W. H. Howe, The Foxboro Co.

Wednesday Afternoon

SYSTEMS I

INDUSTRIAL TELEMETERING

Chairman, P. A. Borden

"Pulse Telemetering for Industry," V. C. Kennedy, Jr., Streeter-Amet Co.

"Automatic Teletype Transmitting System," J. R. Cunningham, Beckman Instruments, Inc.

"Ultra Sonic Liquid Level Indicator System," R. L. Rod, Bogue Electric Mfg. Co.

"Channels for Telemetering, Supervisory Control and Other Purposes," H. A. Rhodes, A. T. & T.

"Telemetering System for Space Position Data," R. N. Nicola, The Newton Co.

COMPONENTS II

PICK-UPS AND TRANSDUCERS

Chairman, K. M. Uglow

"Vibrotron Digital Telemetering System," J. Ohman, Southwest Research Inst.

"A Commutatorless Direct Current Motor," H. D. Brailsford, Brailsford & Co.

"Precision Data Recording and Repeating System (The Inductosyn)," J. L. Winget, Farrand Optical Co.

"A Gravity Switch," P. Weaver, W. L. Maxson Corp.

"A Phase Modulated Transistorized Pressure or Acceleration Telemetering Channel," A. I. Dranetz and J. L. Upham, Gulton Mfg. Corp.

"New Developments in Miniature Telemetering Pick-Ups," L. A. G. TerVeen, Pacific Division, Bendix Aviation Corp.

Thursday Morning

SYSTEMS II

FLIGHT TESTING

Chairman, C. A. Taylor

"New AKT-6 Flight Test," J. E. Spooner, Radiation, Inc.

"Telemetry as a Flight Test Instrument," J. J. Dover, Air Force Flight Test Cntr., Edwards A. F. B.

"A PDM-FM Telemetering System for Low Level DC Inputs," R. H. White, Natl. Advisory Committee for Aeronautics, Langley Aeronautical Lab., Langley Field.

"An Analog Cross-Spectrum Analyzer for Telemetering," R. L. Kenimer, Natl. Advisory Committee for Aeronautics, Langley Aeronautical Lab., Langley Field.

"Automatic Digital Recording of Flight Test Data," L. I. Goldfischer and S. G. Cohen, General Precision Labs.

Thursday Afternoon

SYSTEMS III

MULTIPLEXING TECHNIQUES

Chairman, E. L. Gruenberg

"Mechanical Sampling Devices in Telemetering and Related Fields," J. F. Brinster, General Devices, Inc.

"A New Subminiature Airborne FM Demultiplexer," L. Finkel, F. Shandelman, and J. Piontkowski, Raymond Rosen Engineering Products, Inc.

"The Magnetron Beam Switching Tube," H. Moss, Burroughs Corporation Research Center

"A Mercury Jet Commutating Switch, W. R. Davis, Detroit Controls Corp.

"Miniaturized Airborne Electronic Commututator," R. O. DuBois, Electro-Mechanical Rsearch, Inc.

"Telemetry Filters and Their Effect on the Dynamic Accuracy of Multiplex FM Subcarrier Instrumentation Systems," G. S. Sloughter, R. A. Bunyan, W. H. Duerig, and G. E. Tisdale, Electro-Mechanical Research, Inc.

COMPONENTS III

NEW DEVELOPMENTS IN TELEMETRY AND REMOTE CONTROL

Chairman, J. T. Mengel

"Mixing Airborne Telemetering Subcarriers for Maximum Isolation with Minimum Loss," W. F. Link, Pacific Division, Bendix Aviation Corp.

"A New Ground Station Telemetering Receiver," M. S. Redden and H. W. Zancanata, Nems-Clarke, Inc.

"The Use of AC Excited Gages in a PDM/PM Telemeter System," W. F. Carmody, Pilotless Aircraft Division, Boeing Airplane Co.

"A New Instrumentation Direct Writing Recorder and its Application to Telemetry," G. E. Bower, Century Electronics Co.

"Precision Multi-Channel Heads for Magnetic Tape Recording," A. V. Gangnes, Ampex Corp.

"A Digital Approach to Telemeter Testing," C. R. Reid, Aerophysics Dept., Goodyear Aircraft Corp.

"An Automatic Landing System for Aircraft," M. H. Goldstein, Jr., and C. W. Merrian III, M.I.T.

Dinner

Speaker: Dr. Hugh L. Dryden, Director, National Advisory Committee for Aeronautics

"Problems in Ultra High Speed Flight"

Friday Morning

SYSTEMS IV

NEW DEVELOPMENTS IN TELEMETRY AND REMOTE CONTROL

Chairman, W. J. Mayo-Wells

"Radar Beacon Telemeter," J. W. Poliseo, Stavid Engineering, Inc.

"Flight Control Group AN/DRA-2," W. H Eggerton, Melpar, Inc.

"A Pulse Telemetering System for Use on Balloon-Launched Rockets," L. R. Davis, Naval Research Lab.

"The AN/DKT-4 and AN/MKR-1 Telemetering System," T. B. Jackson, U. S. Naval Ordnance Lab.

"Silicon Transistor Applications in Telemetering Equipment," C. E. Earhart and O. A. Becklund, Texas Instruments.

"Coherent Pulse Telemetry," A. H. Cooper, E.M.I. Engineering Development, Ltd., Hayes, Middlesex, England

Luncheon

Speaker: Dr. William A. Wildhack, National Bureau of Standards

"In-Accurate Transmission of Mis-Information"

Friday Afternoon

COMPONENTS IV

DATA PROCESSING

Chairman, C. F. West

"The Role of Magnetic Tape in Data Recording Processing and Analysis," G. L. Davies, The Davies Laboratories, Inc.

"Talking to a Computer," R. F. Shaw, Electronic Computer Division, Underwood Corp.

"A Precision Pressure Telemetering System with Digital Data Handling," J. Prast, Bell Aircraft Corp.

"An Automatic Digital Data Reduction System Utilizing PDM Telemetering," R. F. Hummer, R. M. McClung, and D. J. Simmons, U. S. Naval Ordnance Test Station, Inyokern Aviation Ordnance Dept., China Lake, Calif.

"Data Reduction Equipment Used with the FALCON Missile," H. D. Greif, Hughes Research & Development Laboratories, Hughes Aircraft Co.

Abstracts of Transactions of the I.R.E.

The following issues of Transactions have recently been published, and are available from the Institute of Radio Engineers, Inc., 1 East 79 Street, New York 21, N. Y., at the following prices. The contents of each issue and, where available, abstracts of technical papers are given below.

Sponsoring Group	Publication	Group Members	IRE Members	Non-Members*
Aeronautical and Navigational Electronics	Vol. ANE-1, No. 4	$1.00	$1.50	$3.00
Audio	Vol. AU-3, No. 2	.95	1.40	2.85
Electronic Computers	Vol. EC-3, No. 1	1.10	1.65	3.30
Reliability and Quality Control	PGQC-4	1.20	1.80	3.60
Telemetry and Remote Control	PGRTRC-2	0.95	1.40	2.85
Proceedings of the WESCON Computer Sessions		1.45	2.15	4.35

*** Public libraries and colleges may purchase copies at IRE Member rates.**

AERONAUTICAL AND NAVIGATIONAL ELECTRONICS

Vol. ANE-1, No. 4, December, 1954

Editorial—K. E. Black

Electronic Simulators for Study of Aircraft Flight Paths—S. L. McDonough. The simulation facilities described in this paper were developed at the Cornell Aeronautical Laboratory, Inc. in Buffalo, N. Y. under the sponsorship of the U. S. Navy Bureau of Ships. The simulator was designed for use as an aid in the study of the problems of coordinating many aircraft in a given geographic area. Correspondingly, the equipment is only as sophisticated as the requirements of the special problem dictated. The main significance of the simulator lies in its ability to develop with a small operating crew, a complex aircraft traffic situation as might be viewed by a ground based surveillance radar. Further, the simulator is capable of generating signals for use in testing and developing experimental data processing, computing, and recording equipment.

Several methods of simulating simplified aircraft tracks in three dimensions are included. Simulation equipments based on these methods are in use as data sources for track-while-scan radar repeater presentation and for direct use in ground installed computing and recording equipment. The methods involve both integration and multiplication techniques in generating voltages which represent tracks in rectangular coordinates. The voltages may be used directly in computers, or video circuits may be employed to convert aircraft position to polar form for PPI and RHI presentation. The simulation methods vary in the degree of aircraft maneuverability from non-maneuvering straight-line aircraft to that of fixed rate of turn aircraft. The complete installation has the capacity to simultaneously generate 24 aircraft paths.

High Voltage Problems in Flush and External HF Antennas—R. L. Tanner. At frequencies near the low end of the hf band the radiation resistance of aircraft antennas is almost always very small compared to antenna reactance. To radiate appreciable power, therefore, large voltages must be applied to the antenna terminals, resulting in a severe voltage breakdown problem at the high operating altitudes of modern aircraft. This paper discusses the mechanisms of breakdown at radio frequencies and relates them to the problem of voltage protection of cap-type and fixed wire antennas and associated components. The use of models in the design of cap-type antennas for high breakdown voltage is considered, and experimental data are given on rf breakdown voltage as a function of altitude for typical geometries.

Development of the Ring Goniometer for Radio Direction Finders—Yoji Ito and Isokazu Tanaka. The radio direction finder of the Bellini-Tosi type requires a radiogoniometer to compare the direction of wave arrival to that of the rotating angle of the search coil. The newly designed Ring Goniometer described is the most efficient developed thus far due to high coupling coefficient (70–80%) and low coupling or octantal error (one degree without correction). It is simple to construct, consisting of two coils which are wound on ring-shaped concentric iron cores.

This paper presents the detailed theoretical analysis and method of measurement of such a ring goniometer.

A New Airborne DME Interrogator Designed for Stable Operation and Ease of Maintenance—A. R. Applegarth. This paper describes the technical design of the NARCO Model UDI-1 DME Interrogator. The transmitter section consists of a ten channel crystal controlled oscillator followed by a chain of amplifier-frequency multipliers to provide 500 watts pulse output in the band 960 to 990 mc. The receiver section is a ten channel superheterodyne using a crystal controlled local oscillator, which operates in the band 1185 to 1215 mc. The range unit contains electronic ranging circuitry along with improved magnetostriction delay code and decode systems, an extremely simple identity signal detector, and a novel means for causing intentionally irregular interrogations. The mechanical design which permits the set to be easily separated into its major components for maintenance is also described.

AUDIO

Vol. AU-3, No. 2, March-April, 1955

IRE-PGA News

A Versatile Audio Spectrometer—W. O. Essler. A new method of obtaining audio power spectra is described. Advantages of the new method are speed of use and great frequency of detail. The new method is based on the production of a "composite signal" which has a time continuous power spectrum. The composite signal method can be used with many types of signals such as speech, music, traffic noise, et cetera.

Triode Cathode-Followers for Impedance Matching to Transformers and Filters—T. J. Schultz. The material presented in this paper gives a selection of ready-made triode cathode follower circuits applicable to the problems of impedance matching to audio filters and transformers. Curves resulting from breadboard tests are given on five tube types, and an illustrative example is included.

Noise Analysis with a Heterodyne Type Sonic Analyzers—J. D. Richard, Jr., P. Smith, and F. H. Stephens. A technique for obtaining noise spectrum levels using a heterodyne type sonic analyzer is described. The analysis of a specific noise recording is shown as an example. A method is also described for obtaining spectrum levels directly from the cathode ray tube photographs.

Basic Principles of Stereophonic Sound—W. B. Snow. Stereophonic sound has become of vital importance to industry. The subject has been studied for many years, but the published material is scattered. This paper summarizes the fundamental theory underlying stereophonic sound so far as it has been published, and gives examples of how the theory is employed in representative practical situations. Fundamental differences between ordinary binaural listening and stereophony are pointed out, as well as similarities. It is shown that much qualitative but little quantitative information has been reported. Factors which aid some stereophonic effects are shown to be detrimental to others, and methods of minimizing the undesirable conditions are suggested. Applications to recording are discussed.

ELECTRONIC COMPUTERS

Vol. EC-4, No. 4, March, 1955

News

Reviews

Engineering Description of the ElectroData Digital Computer—J. C. Aldrich. The operation of the ElectroData digital computer, control console, input-output equipment, and power units is described. The chief logical components are described in detail and the characteristics of some circuits are given, with a description of logical operation. Basic design decisions are stated.

Transistor Circuitry for Digital Computers—C. L. Wanlass. Transistor circuitry is presented that enables the construction of a digital computer which will operate at a clock frequency of 200 kc or less. The circuitry employs readily available germanium or silicon junction transistors of the type used in audio-frequency circuit work. A new system of diode gating is also presented as a necessary part of the circuit philosophy. No vacuum tubes are required or used with the computer.

A High Speed Permanent Storage Device—J. M. Weir. This paper describes a device useful for the permanent storage of digital information which ordinarily is not to be altered once it is stored. The device utilizes a large

magnetic-core matrix switch, of a type described by Rajchman, in conjunction with a storage system used with the Bell Computer, Model VI, to obtain permanent storage capacities up to about a million bits. The information is stored by suitability lacing a set of drive leads from the output of the magnetic switch through an array of magnetic cores. This device is characterized by low-access time, large-operating tolerances, and a relatively small number of magnetic cores.

Control Features of a Magnetic-Drum Telephone Office—W. A. Malthaner and H. E. Vaughn. Several functional arrangements useful in conjunction with a parallel magnetic-drum memory are described with general reference to their application in an experimental telephone-switching system. The functions included are detection and registration of input information, counting, timing, transfer of information from one drum location to another, and translation of information from one form to another.

Stability of a Method of Smoothing in a Digital Control Computer—W. Karush. In a certain operation a digital computer was used as an element of a control system to smooth consecutive observational data. The method of smoothing consisted or predicting from past smoothed values and then combining the prediction with the next observation. In this paper an analysis of the stability of this useful method is made, and an explicit formula of the range of the parameters for which the method is stable is derived. Also, the statistical variance of the smoothed variable is calculated.

Review of Electronic Computer Progress During 1954—D. A. Brown.

RELIABILITY AND QUALITY CONTROL

PGQC-4, December, 1954

Developments in Trustworthy-Value Techniques—E. G. Rowe and P. Welch. Quality-Control procedures in the manufacture of vacuum tubes, with particular emphasis on those designed for reliable or trustworthy service, are discussed. Histograms are used to distinguish between manufacturing variations and manufacturing errors to aid in their rapid detection and correction. Tests are made for short-circuits, disconnections, glass faults, premature heater and emission failures, noise, and short lives under high shock and vibration environment.

Reliability of Quantity Produced Transistors in Low Power Audio Applications—F. M. Dukat. Transistors have now been in quantity production for more than eighteen months and many hundreds of thousands of transistors have been put into daily use in hearing aids and other applications and are giving highly satisfactory and reliable service. A great deal of information has been accumulated relating to the performance of transistors at initial installation and during thousands of hours of operation.

Data will be presented summarizing this experience. The nature of defects that have been encountered will be discussed together with the relation of circuitry and other operating conditions to service performance and reliability.

Reliable Electronics Through Protective Coating Techniques—E. R. Gamson and H. Henesian. Stanford Research Institute has been engaged in a program involving studies and methods of protective coating materials. The techniques investigated, including thin coatings, cast-resin embedment, and foam-plastic encapsulation, were found to offer effective methods for improving the reliability of electronic systems. The protective medium surrounding such equipment could, in the ideal sense, eleminate failures due to vibration, moisture, or other environmental effects.

The results of these studies indicate the degree of protection now offered and the direction whereby the ideal may be obtained. Our research indicates that it is now possible to operate critical electronic devices in adverse environmental conditions for extended periods, by the application of the correct protective coating system.

Quality in Production—Dr. R. Weller. The quality of the product delivered by a manufacturer is largely determined by management policy. Where high quality is desired it is important to direct attention to ways and means of getting it.

The cost of an article from the user's point of view is a function of performance and reliability. The marginal value of improved performance is difficult to evaluate but the marginal value of increased reliability is readily stated.

Reliability can be discussed in terms of the reasons for failure, the identification and analysis of specific causes, the remedies necessary and especially the organizational steps necessary to ensure adequate flow of information and authority to secure a good product.

TELEMETRY AND REMOTE CONTROL

PGRTRC-2, November, 1954

Delay Line Controlled Subcarrier Discriminator—K. A. Morgan and R. F. Blake. A new FM subcarrier discriminator utilizing a delay line as the frequency stable element has been developed. The design has exceptionally good linearity and stability without requiring parts selection. The output is essentially independent of tube characteristics since the sensitivity is primarily determined by a regulated reference voltage and the delay line. The linearity is theoretically perfect and in practice, linearities of plus or minus 0.1% have been obtained when used as a subcarrier telemetering discriminator. Input signal amplitude variations over a dynamic range of 100:1 have no noticeable effect on the output. This discriminator is particularly useful at high frequencies up to 1 mc (where other types of linear discriminators are difficult to construct) and as low as 3 kc. This low frequency limitation may be overcome by the design of miniature lumped constant or disturbed delay lines. Subminiaturization techniques are directly applicable to the design which requires only six tubes and a minimum number of electrical components.

Telemetering and Information Theory—Frank W. Lehan. Issue is taken with the reaction that seems to be in evidence among some radio engineers to the effect that information theory is an extremely complex and somewhat impractical subject fit only for mathematicians to amuse themselves with.

By way of illustration, a short engineering style discussion is given about the misbehavior of the audio frequency discriminator common in fm-fm telemetering at weak signal levels. An intuitive presentation is made as to why such misbehavior is not basic to the fm-fm system but is characteristic of the discriminator used. A different type of discriminator, suggested by information theory, is described and its performance outlined.

The discussion is extended to the fm transmitter. Receiver link and methods of improving the performance of this combination at poor signal to noise levels are suggested. It is speculated that some 10 db improvement may be possible here.

Finally, speculation concerning the possibilities of an integrated fm-fm transmission-reception system capable of operating at greatly reduced signal levels is indulged in. It is emphasized that such speculation is merely an indication of possible fruitful avenues of research, not a proposal for an actual system.

A Temperature-Stable Transistor VCO—Fred M. Riddle. A transistor oscillator which is stable up to 150°F has been developed for obtaining electrical measurements. A reactance-modulation technique uses time rather than gain to control the frequency shift. Reactive current of constant amplitude is applied to an lc circuit for a controlled portion of each cycle. The portion of the cycle is controlled by a bias current injected into the modulating transistor. A differential converter circuit which functions also as a dc amplifier is used with the oscillator in making voltage measurements at high impedance level. Drift of the unit with variation in temperature, vibration, and supply voltage is comparable to that of vacuum-tube multi-vibrators and dc-amplifier combinations.

A Slope Modulator for FM Recording of Analog Data on Magnetic Tape—Louis W. Erath and Frank C. Smith, Jr. A new method of accomplishing frequency modulation enables this system to be used for the recording of analog data on magnetic tape with high signal-to-noise ratio and good linearity.

Conventional means of accomplishing frequency modulation, e.g. multivibrators, suffer from a number of limitations, especially in deviation ratio and linearity. Such circuits are much less elegant than the frequency-meter type of demodulator used in association with them.

The Slope Modulator described in this paper is a new circuit equal in refinement to the demodulator. Theoretically capable of 100 per cent deviation, it is operated in geophysical equipment at 75 per cent deviation for 100 per cent modulation, and in this application distortion is less than 1 per cent with noise down 80 db. Good carrier-frequency stability and freedom from tube characteristics are other features of the circuit.

The Slope Modulator shows promise for applications in telemetering, process control, vibration analysis and laboratory measurements where analog data must be recorded for reproduction. In its present form the system is capable of recording frequencies from zero to 500 cycles at a tape speed of $7\frac{1}{2}$ inches per second. A maximum input signal to the modulator of 10 volts rms or 28 volts dc can be handled with less than 1 per cent distortion and an over-all signal-to-noise ratio (including tape drive mechanism) of approximately 56 db.

PROCEEDINGS OF THE WESCON COMPUTER SESSIONS

A Dependent Variable Analog Function Generator—C. J. Savant, Jr., and R. C. Howard. An all electronic, versatile, analog, arbitrary function generator which permits the rapid change of the functional form over a wide range is described. The basic components are explained with the aid of response oscillograms. The heart of the system is a linear-to-logarithmic converter which displays dependable performance when operating on the nonlinear portion of triode characteristics. After a slide-augmented description of the hardware, various nonlinear equations, including that of Duffing and Van de Pol, are mechanized and the solutions compared with analytical results.

Automatic Iteration on an Electronic Analog Computer—Louis B. Wadel. This paper discusses the employment of an electronic analog computer for automatic solutions of ordinary differential equations whose computer solution depends upon the application of an iterative process. Three types of equations falling in this category are noted, and a simple example of each is given. A computer solution procedure applicable to each example is outlined, with circuit diagrams included. Also described is the

use of a multipole stepping relay to effect the iteration procedures required. Illustrative results are presented.

A Logarithmic Voltage Quantizer—E. M. Glaser and H. Blasbalg. An analog to digital converter is described which converts a voltage into a chain of pulses whose number is proportional to the logarithm of the voltage. The device is automatic. It can handle input data at the rate of 10,000 voltage samples per second. Samples of amplitude between 3.3 and 100 volts and length greater than .3 microseconds can be quantized. Accuracy of conversion is adjustable to either 5 per cent or 10 per cent. A simple rc circuit performs the logarithmic conversion. The mathematical analysis of the conversion and quantization is given. Design equations are developed. A laboratory model of the quantizer is described and experimental results are shown.

A Digital Converter—J. B. Speller. A digital converter, which uses a unique disk pattern, has a shaft rotation input and unambiguous output in the natural binary code. The unit has 13 binary digits with an accuracy of one part in 2^{14}. By adding additional gear trains and disks it is possible to provide considerably higher count and accuracy. No transformations are required to obtain the natural binary code output. The input torque is about 0.2 in oz. and is uniform throughout the range of the instrument. Sixty-four revolutions of the input shaft are needed for the complete count. The converter weighs less than 7 oz. and is similar in appearance to a small synchro. Brushes and commutator disks permit either dc or pulse voltage inputs and outputs.

Efficient Linkage of Graphical Data and Digital Computers—E. D. Lucas, Jr. This paper discusses the problem of transferring graphical data into digital form, and the converse problem of converting digital data into graphical form, for use with digital computers. Semiautomatic machines are described for analyzing and reading both oscillographs and film records, and associated machines for converting these readings into digital form. The latter includes conversion devices with digital output on punched tape, punched cards, or magnetic tapes. Several automatic plotting machines are described which present in graphical form the results of digitally computed data. These plotters will accept computer input in numerous digital forms, both serial and parallel, including punched tape and cards and electrical signals from contact closures. The plotters also accept input from analog devices.

Transistor Flip-Flops for High-Speed Digital Computers—Edmund U. Cohler. This talk sketches the design and operation of various point-contact transistor flip-flops for use in computors. The analysis of the various types are explained and the circuits discussed in terms of their limitations and capabilities. Schematics for these flip-flops are presented and salient differences noted.

A system using various flip-flops and associated gates is described and evaluated in terms of extended use of transistors in computor circuitry.

Design Fundamentals of Photographic Data Storage—Gerhard L. Hollander. This paper is designed to give in one place sufficient background in the fundamentals of photography to permit engineers to evaluate film as a storage medium. The first section briefly presents the terminology and discusses available specifications which characterize films intended primary for ordinary photography. With this background material the data needed to use film for data storage are described. Once these characteristics are determinated, a design procedure can reply experimental development, and the memory transfer function of photographic media can be formulated. Finally, the separate problem of selecting the storage locations in photographic media is treated.

Pulse Response of Ferrite Memory Cores—James Robert Freeman. The response of magnetic-ferrite cores to current pulse in a two-to-one selection coincident-current magnetic-memory are classified as fourteen basic voltage outputs. These outputs are defined and described with relation to the hysteresis loops and pulse sequences involved. Photographs of the pulse responses are presented and certain distinctive differences compared. The concept of reversible and irreversible outputs is explained. Measurements of the various core voltage outputs for the General Ceramics body MF-1326B are given. Curves are included of the pulse voltage characteristics, and the switching and peaking times versus the driving current. An example is given of the use of pulse test data for evaluating the merit of a memory core. Disturb sensitivity is defined and its relationship to the driving pulse duration and overdriving is described. The effect driving pulse rise time also is considered.

Computer-Programmed Preventive Maintenance for Internal Memory Sections of the ERA 1103—S. R. Cray. Daily preventive maintenance routines for the electrostatic and magnetic drum storage systems of the ERA 1103 have greatly reduced the probability of storage failures during subsequent operation. Diagnostic test programs and marginal checking features are described which are used during preventive maintenance periods to insure that satisfactory operating margins prevail. Results obtained through the use of these procedures are presented. The general characteristics of the storage systems are discussed together with operational limitations.

An Input-Output System for a Digital Control Computer—L. P. Retzinger. A control system involving twelve input functions and fourteen output functions using a digital computer as the computation element is discussed. A method of converting shaft rotations to serial binary information, time sharing the basic circuitry, is described. In going from serial digital control signals to output shaft positions a novel system is used to generate and store semi-proportional positioning signals which serve as inputs to magnetic amplifiers. Throughout the system, time sharing is utilized to a high degree, and independence of supply voltage, temperature, and other factors normally affecting analog systems, is stressed.

Characteristics of a Logistics Computer—Eugene Leonard. The ORDFIAC, a large-scale computer having punched-card input and output and a 10,000 word magnetic drum memory, was built to handle supply problems for the Ordnance Department of the Army. Its code includes an unusual and highly versatile vector instruction, which in addition to its original purpose of facilitating matrix manipulation has proved very useful for a wide variety of operations. The 100 channels of the memory are relay-selected, with relay operation thoroughly checked before each transfer of information into or out of the memory. The paper also will discuss design features and operating experience.

The Dico 20 Digital Differential Analyzer—Floyd Steele. Dico 20 is a twenty integrator magnetic drum differential analyzer. The four information channels are interplexed to form two recirculating channels. Trapezoidal integration is used. Integrator numbers are 20 significant digits long. Complete integrator communication exists and either the dx or dy integrator inputs may be multiple. Decoding is accomplished for multiple inputs by non-numerical addition. Variables are represented and processed as difference numbers. Decision is achieved by an ordinary integrator.

Dico 20 has 6 logical flip-flops and 4 memory flip-flops. There are 180 logical diodes. Conventional computer techniques are used in electronic design. The drum speed is 30 rps. and the clock rate is 50 kc.

The Bendix General Purpose Computer—D. C. Evans and H. D. Huskey. The Bendix Model G-15 is a general purpose, stored program computer having exceptional computing efficiency. The logical design incorporates innovations which permit a substantial reduction in the physical side and complexity.

The novel command structure permits effective use of sub-routines and minimum access coding. It has commands for addition, subtraction, multiplication, and division of both single and double length words. Commands for branching and other logical operations are incorporated. The memory has a capacity of more than 2000 words including a section with 0.6 millisecond average access time.

Input-output facilities may operate concurrently with computation and include electric typewriter, punched paper tape with photo-electric reader, magnetic tape, and adapter for punch cards.

Abstracts and References

Compiled by the Radio Research Organization of the Department of Scientific and Industrial Research, London, England, and Published by Arrangement with that Department and the *Wireless Engineer*, London, England

NOTE: The Institute of Radio Engineers does not have available copies of the publications mentioned in these pages, nor does it have reprints of the articles abstracted. Correspondence regarding these articles and requests for their procurement should be addressed to the individual publications, not to the I.R.E.

The Index to the Abstracts and References published in the PROC. I.R.E. from February, 1954 through January, 1955 is published by the PROC. I.R.E., April, 1955, Part II. It is also published by *Wireless Engineer* and included in the March, 1955 issue of that journal. Included with the Index is a selected list of journals scanned for abstracting with publishers' addresses.

The number in heavy type at the upper left of each Abstract is its Universal Decimal Classification number and is not to be confused with the Decimal Classification used by the United States National Bureau of Standards. The number in heavy type at the top right is the serial number of the Abstract. DC numbers marked with a dagger (†) must be regarded as provisional.

U.D.C. CHANGES

In anticipation of a new edition of the Universal Decimal Classification Abridged English Edition (BS 1000 A), certain changes in U.D.C. numbers will be made in this and subsequent issues. The new numbers used will be:

- Radio astronomy: 523.16
- Ultrasonics: 534 subdivisions with the special analytical subdivision -8 attached
- Sound recording and reproducing: 534.85
- Electroacoustic problems, transduction, etc.: 534.86

ACOUSTICS AND AUDIO FREQUENCIES

534.121.2:621.395.61 **602**

Theory of the Effect of a Thin Air Film on the Vibrations of a Stretched Circular Membrane—D. H. Robey. (*Jour. Acous. Soc. Amer.*, vol. 26, pp. 740–745; September, 1954.) Analysis generally applicable to conditions in capacitor microphones is presented. Application of the results to the case of a particular miniature microphone with titanium diaphragm shows that the effective stiffness at 20 kc is 15 times that at 5 cps.

534.132 **603**

Radial Vibrations of Thick-Walled Hollow Cylinders—J. A. McFadden. (*Jour. Acous. Soc. Amer.*, vol. 26, pp. 714–715; September, 1954.) Approximate formulas are given for the natural wavelengths.

534.213.4 **604**

The Propagation of Elastic Waves in Thin-Walled Cylindrical Shells—M. C. Junger and F. J. Rosato. (*Jour. Acoust. Soc. Amer.*, vol. 26, pp. 709–713; September, 1954.) Analysis indicates that there are two possible modes of propagation in the axial direction; at high frequencies the one corresponds to flexural waves and the other to longitudinal waves. The dispersion curves are in good agreement with published experimental results. The results are relevant to investigations of cylindrical $BaTiO_3$ transducers and to the problem of sound insulation by lightweight partitions.

534.213.4:534.6 **605**

Propagation of Sound in Narrow Tubes—H. W. Helberg. (*Akus. Beihefte*, no. 2, pp. 578–586; 1954.) Theory is developed yielding the formulas of Rayleigh and Kirchhoff as limiting cases. The accuracy of Kirchhoff's expression for the attenuation is improved by addition of a constant. Using a tube of cross section 1.03 $\times$19.4 mm with suspended particles as indicator, measurements were made of attenuation, sound velocity, and transverse distribution of particle velocity; the results give considerable support to the theory.

534.213.4:534.833.4 **606**

Propagation of Sound over Single Absorptive Strips in Ducts—J. E. Young. (*Jour. Acous. Soc. Amer.*, vol. 26, pp. 804–818; September, 1954.) A method is developed for predicting the absorptive effect of the strip, with accuracy sufficient for practical purposes, by a combination of approximations involving assumptions about the potential distribution at the surface of the strip. In the case of resonant absorbers with low dissipation, the attenuation can be calculated simply and accurately for strips of sufficient length, found experimentally to be about four times the duct diameter. Predictions can be made for porous strips in the same length range if the appropriate phase parameter is determined.

534.23 **607**

An Exact Method for determining the Directivity Index of a General Three-Dimensional Array—E. Rhian. (*Jour. Acous. Soc. Amer.*, vol. 26, pp. 704–706; September, 1954.)

534.26 **608**

Diffraction of an Acoustical Wave Obliquely Incident upon a Circular Disk—H. S. Heaps. (*Jour. Acous. Soc. Amer.*, vol. 26, pp. 707–708; September, 1954.) Calculated values of the sound pressure behind the disk with an obliquely incident wave are compared with those with a normally incident wave.

534.61:621.395.61 **609**

Ceramic Probe Microphones—E. Ackerman and W. Holak. (*Rev. Sci. Instr.*, vol. 25, pp. 857–861; September, 1954.) Report of a study of two types of microphone used for measuring intense sound fields at frequencies in the range 6–100 kc. The sensitive element is a $BaTiO_3$ cylinder 1/16 inch in length and in over-all diameter. Calibration procedures are described.

534.612.4 **610**

Pressure Calibration of Condenser Microphones above 10,000 c/s—B. D. Simmons and F. Biagi. (*Jour. Acous. Soc. Amer.*, vol. 26, pp. 693–695; September, 1954.) "A 'plane wave' acoustic coupler and an electrical admittance method are described for the pressure calibration of condenser microphones in the ultrasonic frequency range."

534.614–8 **611**

Rapid-Indication Ultrasonic Interferometer—L. Bergmann. (*Akus. Beihefte*, no. 2, pp. 591–593; 1954.) Measurements of the velocity of sound in gases and liquids are made quickly using a decade counter tube to count the number of maxima traversed as the interferometer reflector is shifted through a given distance.

534.62+621.317.3.029.63 **612**

Construction of a Reflection-Free Room for Sound Waves and Decimetre Electrical Waves—G. W. Epprecht, G. Kurtze and A. Lauber. (*Akus. Beihefte*, no. 2, pp. 567–577; 1954.) Description of a room constructed at Berne, having inner dimensions 5$\times$4.4$\times$2.6 m, lining depth 60 cm and acoustic cut-off frequency 120 cps. To make the lining absorbent for em waves, steel wool is used rather than the graphite used in the anechoic chamber at Göttingen [942 of 1954 (Meyer et al.)]. The floor is netting made of perlon cables of diameter 4 mm.

534.785 **613**

Some Factors affecting Multichannel Listening—J. P. Egan, E. C. Carterette and E. J. Thwing. (*Jour. Acous. Soc. Amer.*, vol. 26, pp. 774–782; September, 1954.) An experimental investigation is reported of the intelligibility of a wanted speech message in the presence of an unwanted speech message. Use of a high-pass filter in either of the two channels improved intelligibility. The advantages of dichotic presentation were demonstrated. Masking of speech by noise was also investigated.

534.832:534.121.1 **614**

Sound Radiation from a Wall excited to Flexural Vibrations—W. Westphal. (*Akus. Beihefte*, no. 2, pp. 603–610; 1954.) By using the "radiation coefficient," whose value can be found approximately from theory developed by Gösele (949 of 1954), an estimate can be made of the sound energy radiated from a plate from measurements of the amplitude of flexural vibrations. A determination of the lateral transmission in building acoustics can hence be made.

534.833.4 **615**

The Multiple-Panel Sound Absorber—E. C. H. Becker. (*Jour. Acous. Soc. Amer.*, vol. 26, pp. 798–803; September, 1954.) Equivalent-circuit analysis is presented for multiple-panel absorbers; increasing the number of elements increases the absorption bandwidth, particularly at low frequencies. An example is described of a particular construction giving satisfactory results.

534.84 616
Review of Architectural Acoustics during the Past Twenty-Five Years—V. O. Knudsen. (*Jour. Acous. Soc. Amer.*, vol. 26, pp. 646–650; September, 1954.)

534.84 617
Definition and Diffusion in Rooms—E. Meyer. (*Jour. Acous. Soc. Amer.*, vol. 26, pp. 630–636; September, 1954.) The importance of diffusivity as a criterion of acoustic quality is indicated in an account of architectural acoustics research at Göttingen. The product of definition and diffusivity may prove to be a useful figure of merit.

534.84 618
The Statistical Parameters of the Frequency Response Curves of Large Rooms—M. Schröder. (*Akus. Beihefte*, no. 2, pp. 594–600; 1954.) Frequency response curves are obtained using a variable-pure-tone generator and a microphone at different pairs of separated points in the room. Calculations are made of the rms response fluctuation, the mean height of the peaks, the mean spacing of the zero points (intersections of response curve with mean level), the mean spacing of the peaks, the mean phase rotation per cps, and the "frequency irregularity."

534.84 619
The Frequency Dependence of the Sound Pressure in Rooms—H. Kuttruff and R. Thiele. (*Akus. Beihefte*, no. 2, pp. 614–617; 1954.) Measurements made on 19 rooms under different conditions are reported, using stationary excitation. Analysis of the frequency response curves over the range 70–4000 cps indicates that the mean difference of level between successive maxima and minima amounts to 9–10 db, irrespective of room volume or reverberation time. The total number of maxima is proportional to mean reverberation time, with a mean fluctuation of 10 per cent. The "frequency irregularity" is thus also proportional to reverberation time.

534.84 620
Experiments for the Determination of Optimum Reverberation Time for Large Music Studios—W. Kuhl. (*Akus. Beihefte*, no. 2, pp. 618–634; 1954.) Estimates of optimum reverberation time were made on the basis of over 13,000 individual judgments on different records of three pieces of orchestral music recorded in a number of different rooms with volumes ranging from 2,000 to 14,000 m^3. Reverberation-time/frequency curves derived from the records are presented, together with the frequency analysis of a typical loud chord for each record. Values of reverberation time judged to be optimum for the different types of music are quoted; these values do not depend on studio volume. For an occupied studio the best compromise is 1.7 second; for a small unoccupied studio the best value is considerably higher.

534.84 621
Electroacoustic Characteristics of the Palais des Festivals at Cannes—C. Soulé. (*Rev. Son*, no. 18, pp. 251–252; September/October, 1954.) The measured reverberation-time/frequency characteristic is in general agreement with the theoretical curve for an auditorium of volume 2,000 m^3; the theoretical curve corresponding to the actual volume of 10,000 m^3 lies rather higher. This slight deadening was achieved deliberately by acoustic treatment. Curves of recorded level/frequency in stalls and circle are also given.

534.84:621.395.623.8 622
Sound Systems for Large Auditoriums—L. L. Beranek. (*Jour. Acoust. Soc. Amer.*, vol. 26, pp. 661–675; September, 1954.) This comprehensive review includes consideration of auditorium acoustics, loudspeaker types and arrangements, and psycho-acoustic factors. Reference is made to the sound systems in the University City Hall, Caracas, Venezuela, in the United Nations Headquarters Hall, New York, in a municipal theater, and in the Holy Cross Cathedral.

534.845 623
Advances since 1929 in Methods of Testing Acoustical Performance of Acoustical Materials—F. G. Tyzzer and H. A. Leedy. (*Jour. Acous. Soc. Amer.*, vol. 26, pp. 651–656; September, 1954.)

534.845 624
Possibilities of Error in Measurements of Sound Insulation at Low Frequencies: Part 1—W. Kuhl. (*Akus. Beihefte*, no. 2, pp. 611–614; 1954.) Measurements subsequent to those reported by Becker et al. (311 of 1953) indicate that the methods used may involve appreciable errors at low frequencies, due to (a) standing waves, (b) insufficient size of specimen, (c) natural resonances of the test rooms, and (d) incorrect determination of the absorption surface in the receiving space.

534.845 625
On Sound Absorption by Cylindrical Diffusers—G. Parolini. (*Jour. Acous. Soc. Amer.*, vol. 26, pp. 795–797; *Ricerca sci.*, vol. 24, pp. 1465–1470; July, 1954.) Measurements were made on the acoustic absorption of plywood cylindrical diffusers coated with porous materials, such as glass wool. High absorption was obtained even in the low frequency range, owing to the resonance of the cylindrical plywood frame, and to sound scattering. The experimental values have been found in good agreement with those computed according to Cook and Chrzanowsky's theory.

534.845 626
A Nomogram for Simplification of the Determination of Sound Absorption by the Reverberation-Chamber Method—W. Händler and G. Venzke. (*Akus. Beihefte*, no. 2, pp. 587–590; 1954.) A nomogram based on the Sabine formula is presented and the method of use explained.

534.845.1 627
Comparative Measurements of the Absorption of Sound by Absorptive Materials, using the Tube and Reverberation-Chamber Methods—G. Kurtze and A. Lauber. (*Tech. Mitt. schweiz. Telegr.-Teleph. Verw.*, vol. 32, pp. 249–253; July 1, 1954. In German.) Report of measurements made on some commonly used porous materials, with the object of determining the range of validity of the cosine law of variation of absorption coefficient with angle of incidence, and hence determining the degree of reliance to be placed on results obtained by the simple tube method. Large discrepancies observed between the results by the two methods are probably due to velocity components parallel to the boundary surface and not taken into account in the calculations.

534.845.1 628
Resonance Reverberation Method for Sound Absorption Measurements—J. Karpovich. (*Jour. Acous. Soc. Amer.*, vol. 26, pp. 819–823; September, 1954.) The method described is suitable for measurements on liquids at frequencies from about 20 kc to over 600 kc. Sound absorption coefficients of 44 liquids are tabulated. Application of the method to measurements on solids is mentioned.

534.85 629
A Review of Twenty-Five Years of Sound Reproduction—H. F. Olson. (*Jour. Acous. Soc. Amer.*, vol. 26, pp. 637–643; September, 1954.)

534.85 630
Noise Level and Mechanical Stresses in Plastic Sound Records—E. A. Keller. (*Jour. Acous. Soc. Amer.*, vol. 26, pp. 685–687; September, 1954.) "Residual mechanical stresses in press-polished plastic film material used for the embossing type sound recording are in many cases responsible for relatively high noise levels. Results of noise measurements of different plastic materials on a 400 grooves per inch recorder are presented. The relation between optically observed stresses and recorded noise level is given. Practical consequences are discussed."

534.85 631
Contribution to Analysis of Recording Process in H.F. Magnetic Recorders—O. Schmidbauer. (*Funk u. Ton*, vol. 8, pp. 341–360; July, 1954.) The hf bias recording method is analyzed and the influence of tape type, tape speed, width of recording-head gap and other parameters is discussed. A brief comparison with experimental results is made and reasons for discrepancies are noted. The possibility of indicating the quality of commercial tapes by a code is examined.

534.85:621.395.625 632
Fluctuations of Pitch of Recorded Sounds and Determination of Permissible Limits for Broadcasting—P. H. Werner. (*Tech. Mitt. schweiz. Telegr.-Teleph. Verw.*, vol. 32, pp. 360–362; September 1, 1954. In French.) Methods of measurement of wow and flutter are outlined. Subjective tests have been made of the threshold of audibility for these two effects, using sounds produced by violin, piano and organ, recorded on magnetic tape. Frequency variations of 4 per cent were perceived by highly sensitive listeners.

621.395.61/.62 633
Loudspeakers and Microphones—L. L. Beranek. (*Jour. Acous. Soc. Amer.*, vol. 26, pp. 618–629; September, 1954.) Illustrated survey of developments from 1915 to date.

621.395.61 634
Unidirectional Microphone utilizing a Variable Distance between the Front and Back of the Diaphragm—A. M. Wiggins. (*Jour. Acous. Soc. Amer.*, vol. 26, pp. 687–692; September, 1954.) A gradient microphone is described in which the force acting on the diaphragm is made frequency independent by providing two frequency-selective sound inlets at the back of the diaphragm so that the distance between the front and back inlets is greater for the lower frequencies. Under these conditions the sound-responsive element can be constructed as for a pressure microphone.

ANTENNAS AND TRANSMISSION LINES

621.372.2 635
The Elliptic Surface Wave—A. E. Karbowiak. (*Brit. Jour. Appl. Phys.*, vol. 5, pp. 328–335; September, 1954.) Formulas are derived for *E*-mode propagation on the surface of an elliptic cylinder; in this mode the field decays monotonically as the radial distance in the tranverse plane increases. The relation between this case and that of the surface-wave line with circular cross section is examined; the performance of the latter is shown to be substantially unaffected by slight deformation. Particular types of elliptical guide discussed include (a) the dielectric-coated conducting rod, (b) the rod with rectangular corrugations, (c) the homogeneous metal rod, and (d) the dielectric rod.

621.372.2.029.6 636
High-Frequency Phenomena—W. A. Tripp. (*Wireless Eng.*, vol. 32, pp. 19–25; January, 1955.) It is shown that the introduction of em field analysis is not essential for dealing with hf phenomena, which can be discussed satisfactorily in terms of current and voltage in the same way as lf phenomena; these concepts are applied to examination of the operation of transmission lines, including waveguides.

621.372.8 637
Propagation of Electromagnetic Waves in

Cylindrical Waveguides with Imperfectly Conducting Walls—V. M. Papadopoulos. (*Quart. Jour. Mech. Appl. Math.*, vol. 7, pp. 326–334; September, 1954.) Calculations are made by a perturbation method, using approximate boundary conditions. The imperfectly conducting walls have the effect of removing a particular type of degeneracy occurring in the ideal guide, in which definite linear combinations of *E*- and *H*-modes are propagated with definite propagation constants; this type of degeneracy occurs in rectangular guides. It follows that the power-loss method of calculating the attenuation constant, which assumes pure *E*- or *H*-mode propagation, is not correct in these cases. The perturbation method gives not only the attenuation constant for each combination of modes, but also the value of the phase velocity, and the corresponding field components.

621.372.8 638

An Approximate Method for the Calculation of Propagation Constants for Inhomogeneously Filled Waveguides—L. G. Chambers. (*Quart. Jour. Mech. Appl. Math.*, vol. 7, pp. 299–316; September, 1954.) A variational method is developed which is applicable to waves whose field components are given in terms of one scalar potential, for cases where the electrical constants vary across the waveguide but not along it. The conditions for the existence of pure *TE* or pure *TM* waves in such a guide are considered.

621.372.8 639

Two-Section Transmission-Line Transformer—M. S. Wheeler. (*Wireless Eng.*, vol. 32, pp. 15–18; January, 1955.) Analysis is presented for a waveguide-type impedance transformer convenient for coupling a magnetron to a standard waveguide and comprising two sections of different transverse dimensions. The cases of equal-length and nearly-equal-length sections are treated.

621.372.8:621.317.333.6 640

Electrical Breakdown in Waveguides at 3000 Mc/s—J. W. Sutherland. (*Electronic Eng.*, vol. 26, pp. 538–540; December, 1954.) Development of methods for testing high-power waveguides is described. The power-handling capacity can be improved by using other gases, notably "arcton 6" in place of air.

621.372.8:621.39 641

Waveguide as a Communication Medium—S. E. Miller. (*Bell Sys. Tech. Jour.*, vol. 33, pp. 1209–1265; November, 1954.) The circular-electric mode is particularly advantageous for long-distance communication, since the attenuation coefficient for this mode decreases as the carrier frequency increases; the theoretical value is 2 db per mile for round guide of diameter 2 inches, for frequencies around 50 kmc. Scale-model experiments using guide of internal diameter 4.73 inches and a frequency of 9 kmc are reported. Under favorable conditions the observed losses are within 25 per cent of the theoretical values; the discrepancy is attributed partly to guide roughness and partly to mode conversion at irregularities along the guide. Distortion and crosstalk due to undesired modes can be reduced by means of mode filters; constructions providing continuous filtering are described. A suitable structure comprises a helix or series of metal rings supported in a lossy housing. Problems associated with bends in the guide are examined. Base bandwidths of the order of 500 mc should be possible, using pcm. Regeneration would probably be required at the repeaters; the spacing between repeaters should be about 25 miles.

621.396.67 642

On Isotropic Antennas—H. F. Mathis. (Proc. I.R.E., vol. 42, p. 1810; December, 1954.) Addendum to 37 of 1952.

621.396.67.012.12 643

Radiation from a Point Dipole located at the Tip of a Prolate Spheroid—E. C. Hatcher, Jr., and A. Leitner. (*Jour. Appl. Phys.*, vol. 25, pp. 1250–1253; October, 1954.) Calculations are made of the radiation patterns for spheroidal conductors of various thicknesses, with major axes equal to λ/π, $2\lambda/\pi$ and $3\lambda/\pi$.

621.396.67.029.62 644

Internally Accessible Tubular Masts as Supports for U.S.W. and Television Aerials—W. Berndt. (*Funk u. Ton*, vol. 8, pp. 288–294 and 481–489; June and September, 1954.) Mechanical construction features of support masts for use with antennas for bands I–IV are described. Slot-antenna masts are also discussed and the radiation characteristics of various systems are presented graphically. The account deals mainly with modern German practice.

621.396.674.3 645

Aerials for U.S.W. Broadcasting and Television—W. Stöhr. (*Frequenz*, vol. 8, pp. 240–248; August, 1954.) The application of dipole units for directional and omnidirectional transmissions is illustrated in descriptions of three particular systems: (a) a vhf Yagi with relative bandwidth 1.15:1; (b) a band-III television broadcasting array consisting of stacked groups of four coupled full-wave dipoles, relative bandwidth 1.5:1; (c) a vhf broadcast array built up of units comprising two full-wave dipoles arranged with their two halves at right angles so as to form a square, fitting readily around or within a mast and secured to it at the voltage nodes. Antenna systems at Langenberg and Bogota and those of the Milan-Rome television link are described. Results of an investigation of the effects of ice formation on exposed antennas are noted.

621.396.676.029.62 646

Homing Aerials for Aircraft—S. Zisler and G. Dubost. (*Ann. Télécommun.*, vol. 9, pp. 226–236; September, 1954.)Vhf systems comprising identical parallel cylindrical antennas are discussed. General relations are derived for a quadripole arrangement. Calculations are made of optimum antenna length for homing, and of the ratio between the antenna currents; these calculations are based on defining limits for the form of the radiation pattern. Factors taken into account include antenna sensitivity, represented by the variation of the radiation with direction; precision of indication of the axis, which depends on the symmetry of the system; and the need to avoid spurious indications corresponding to equality of the diagrams for directions other than the true axis.

AUTOMATIC COMPUTERS

681.142 647

DYSEAC—the New N.B.S. Electronic Computer—(*Tech. News. Bull. Nat. Bur. Stand.*, vol. 38, pp. 134–141; September, 1954.) See 39 of 1954 (Elbourn and Witt) and 2320 of 1954 (Leiner and Alexander).

681.142 648

The Effect of Interpretive Techniques on Functional Design of Computers—T. Pearcey, G. W. Hill and R. D. Ryan. (*Aust. Jour. Phys.*, vol. 7, pp. 505–519; September, 1954.) Analysis of the programs for a number of computations performed by the C.S.I.R.O. Mark I computer indicates the feasibility of designing an adaptable and reliable computer having only a relatively small amount of rapid-access erasable store and a larger amount of rapid-access non-erasable store in which would be held all interpretation routines, function blocks, etc. The operator would require no knowledge of the actual machine code, but would place his hyper-programs and data into a slow-speed backing store.

681.142 649

Program Design for the C.S.I.R.O. Mark I Computer: Part 3—Adaptation of Routines for Elaborate Arithmetical Operations—T. Pearcey and G. W. Hill. (*Aust. Jour. Phys.*, vol. 7, pp. 485–504; September, 1954.) Discussion of the extension of the library routine system to deal with floating point, multiple precision and complex arithmetic and certain combinations of these. The "interpretive" method of program organization [1655 of 1952 (Wilkes et al.)] is used. Part 2: 641 of 1954.

CIRCUITS AND CIRCUIT ELEMENTS

621.314.7:[621.37+621.396.621 650

Some Transistor Circuits—A. J. W. M. van Overbeek. (*Tijdschr. ned. Radiogenoot.*, vol. 19, pp. 231–260; September, 1954.) The characteristics of junction transistors are discussed; at frequencies of 1–10 mc the equivalent circuit is already as complicated as that of a thermionic tube at frequencies a hundred times higher. Particular circuits examined include one for a medium-wave broadcast receiver in which the selectivity is automatically increased as the signal strength decreases. It is pointed out that for a peak output power of e.g. 250 mw the consumption is 150–200 mw. Nonlinear distortion in transistors is compared with the corresponding effect in thermionic tubes. The upper frequency limit set by cut-off of current amplification is considered in relation to trigger circuits. A circuit including a *p-n-p* and an *n-p-n* transistor is shown which has properties resembling those of a gas-filled tube with adjustable ignition voltage, short ignition time, very low discharge voltage drop and low discharge noise.

621.316.722.4:537.226 651

Dielectric Potentiometers—G. E. Pihl. (Proc. I.R.E., vol. 42, pp. 1758–1761; December, 1954.) A voltage divider is described comprising a movable electrode and a system of fixed electrodes all immersed in a lossy liquid dielectric, so that the paths between the electrodes are both resistive and capacitive. The arrangement is suitable for wide-band operation (e.g. 20 cps—1 mc), since the product of the equivalent parallel resistance and capacitance is a constant depending only on the nature of the dielectric. Various practical embodiments are described. Desirable characteristics for the dielectric are indicated.

621.316.86:621.396.822 652

Current Noise in Carbon-Film Resistors—K. E. Doering. (*Funk u. Ton*, vol. 8, pp. 378–385 and 422–429; July and August, 1954.) An experimental investigation at audio frequencies is reported. The results are consistent with an empirical formula according to which the current-noise voltage varies approximately directly with current. In a few specimens the noise was found to depend on the direction of current. 45 references.

621.316.89 653

The Resistivity of "Composition" Resistors at Radio Frequencies—U. Tiberio. (Proc. I.R.E., vol. 42, pp. 1812–1813; December, 1954.) Continuation of the previous discussion (654 of 1954) of the mechanism causing the drop of resistance of composition resistors at hf. Experimentally obtained resistance/frequency curves are presented for resistors comprising (a) a cylindrical column of an aqueous solution of sodium chloride, (b) a cylindrical column of an aqueous solution of copper sulphate, and (c) a cylindrical column of carbon /resin composition. The resistance of type (a) is practically constant at frequencies up to 100 mc, while that of types (b) and (c) drops considerably. The drop in the resistance of the composition resistor is ascribed partly to the "resistivity factor," and partly to the "external capacitance factor." It is suggested that a frequency-independent resistor could be obtained by mixing carbon with a material of high dielectric constant.

621.318.4 654

Component Design Trends—High-Fre-

quency Coils use New Core Materials—F. Rockett. (*Electronics*, vol. 27, pp. 140–143; December, 1954.) Points discussed include use of ferrite cores for coils operating at frequencies up to about 100 mc, use of glass and other low-loss materials for formers and use of toroidal constructions.

621.319.4 655
The Capacity and Field of a Split Cylindrical Condenser, using the Method of Inversion—H. J. Peake and N. Davy. (*Brit. Jour. Appl. Phys.*, vol. 5, pp. 316–321; September, 1954.) "The complex potential of a split cylindrical condenser is obtained by inversion of a known, simpler case. Expressions are obtained for the value of the electrostatic field at points on the axes of symmetry, the surface density of charge on a conductor and the capacity of the condenser. The expressions obtained by Adams, using another method, are deduced as one of three special cases for which tables and graphs are provided. The results should prove of value in the design of electrode systems for various purposes."

621.319.42 656
Miniature Lacquer-Film Capacitors—D. A. McLean and H. G. Wehe. (Proc. I.R.E., vol. 42, pp. 1799–1805; December, 1954.) A manufacturing process is described in which a thin film is cast on a supporting base and is metallized and slit while still supported, after which it is stripped and wound into capacitor units. Metallized films 0.1 mil thick have been produced; the resulting capacitors are about a seventh the size of the smallest metallized-paper types. The support may be left in if the film is extremely fragile or if the capacitor is to operate at voltages below about 15 v. A formula is derived for the effective series resistance.

621.372.412 657
Thickness-Shear and Flexural Vibrations of a Circular Disk—R. D. Mindlin and H. Deresiewicz. (*Jour. Appl. Phys.*, vol. 25, pp. 1329–1332; October, 1954.) Antisymmetrical modes of vibration in an AT-cut quartz disk are investigated by considering the simpler corresponding case of an isotropic disk. Differences between the frequency spectrum in this case and in that of the rectangular plate [1861 of 1951 (Mindlin)] are due to the presence of thickness-twist modes in addition to the thickness-shear and flexural modes.

621.372.413 658
Theory of Coupled Endovibrators [cavity resonators]—A. I. Akhiezer and G. Ya. Lyubarski. (*Zh. Tekh. Fiz.*, vol. 24, pp. 1697–1706; September, 1954.) A system of two cavity resonators coupled by means of a narrow slot in their common wall is considered theoretically. Two classes of oscillations are considered: (a) those whose frequencies are determined primarily by the length of the slot and are nearly independent of the shape of the resonators; (b) those whose frequencies are near the frequencies of the oscillations in the resonators when not coupled.

621.372.5 659
The Wien Bridge as a Phase Shifter—J. M. Diamond. (Proc. I.R.E., vol. 42, pp. 1807–1808; December, 1954.) Several circuits are presented illustrating the use of the Wien bridge to provide phase shift with small amplitude change.

621.372.5 660
Networks Attenuation and Input Impedance—R. Talks. (*Wireless Eng.*, vol. 32, pp. 29–30; January, 1955.) Useful formulas are presented.

621.372.54 661
Four-Terminal Networks with Transfer Function having Zeros with Small Real Part—W. Krägeloh. (*Frequenz*, vol. 8, pp. 249–256; August, 1954.) Analysis of low-pass filter networks based on insertion-loss principles [2940 of 1940 and 3226 of 1942 (Bader)] to investigate the effect of "critical" zeros in the transfer-function plot on the reactance to be developed, the accuracy required in the calculation, and the component values.

621.372.622 662
Some Aspects of Mixer-Crystal Performance—P. D. Strum. (Proc. I.R.E., vol. 42, pp. 1806–1807; December, 1954.) Correction to paper abstracted in 2941 of 1953. Please note change of U.D.C. number.

621.373.421.11.016.35 663
Criteria for the Amplitude Stability of a Power Oscillator—W. R. MacLean. (Proc. I.R.E., vol. 42, pp. 1784–1791; December, 1954.) Stability criteria for a tuned-anode oscillator are established in the form of two inequalities derived from differential equations expressing the voltage variations of the grid and anode, and involving the ratio of feed-back power to anode power, the ratio of the time constant of the grid-leak and capacitor combination to the time constant of the tank circuit, and functions of the angles of current flow for grid and anode. Experimental verification of the results using a Type-3*C*24 triode is reported.

621.373.43:517.93 664
Investigation of the Dependence of Natural Frequency of Oscillation on Spectral Composition—I. I. Minakova. (*Zh. Tekh. Fiz.*, vol. 24, pp. 1677–1686; September, 1954.) A particular case of the theory of nonlinear electric oscillations is considered. Writing the solution of the equation $\ddot{x}+\psi(x)\dot{x}+\omega_0^2x=0$ as the sum of $A_k \sin(k\omega t+\phi_k)$, where A_k is the amplitude of the kth harmonic given by the Fourier series, the ratio $\omega^2/\omega_0^2=\sum_1^n A_k^2/\sum_1^n k^2A_k^2$. Using this relation, the dependence of ω on the amplitudes of the spectrum can be calculated. The measured and calculated frequency characteristics of relaxation oscillators agreed well. The results are presented graphically. See also van der Pol, Proc. I.R.E., vol. 22, pp. 1051–1086; September, 1934, for a general introduction.

621.374.4:621.314.63 665
Crystal Frequency Multipliers for Centimetre and Millimetre Waves—L. Grifone. (*Ricerca sci.*, vol. 24, pp. 1870–1879; September, 1954.) Circuits are described for generating harmonics at frequencies >30 kmc, using Type-*IN23B* crystals. The generator is coupled by a cross-bar transition to the crystal, which can be shifted axially for purposes of impedance matching. Higher frequencies can be achieved by use of Type-*IN*26 crystals in a similar arrangement.

621.375.2.018.75 666
On the Faithful Reproduction of the Flat Top of a Pulse in a High Fidelity Pulse Amplifier: Part 2—B. K. Bhattacharyya. (*Indian Jour. Phys.*, vol. 27, pp. 565–577; November, 1953.) An experimental verification is reported of analysis presented previously (3566 of 1953). It was demonstrated that the anode current may sag appreciably if the time constants of the cathode and screen-grid *RC* circuits are not properly chosen.

621.375.223+621.373.421 667
Resonance Circuits comprising RC or RL Elements, and some Applications—H. Müller (*Funk u. Ton*, vol. 8, pp. 471–479; September, 1954.) The frequency characteristics of the Wien bridge and of an analogous inductance bridge are investigated theoretically. Pseudo-resonance phenomena occurring in the neighborhood of bridge balance are discussed. True resonance is obtained when the bridge is associated with a feedback circuit to act as an oscillator. The tuned *RC* amplifier and the *RC* and *RL* oscillators are described.

621.375.23 668
Multistage Amplifier Output Impedance—J. B. Earnshaw. (*Electronic Eng.*, vol. 26, p. 553; December, 1954.) Based on the result that the ratio of the net amplification to the parallel output impedance of a simple amplifier is the same with and without voltage feedback, a simple expression is obtained relating the parallel output impedance to the amplifier constants for the multistage amplifier with over-all feedback. The design of an amplifier with a gain of 1,000 and a parallel output impedance of 1Ω is discussed briefly.

621.375.3 669
Magnetic Amplifiers—G. M. Ettinger. [*Elec. Rev.* (*London*), vol. 155, pp. 348–352; September 3, 1954.] A general survey of types and applications.

621.375.3 670
Three-Phase High-Speed Magnetic Amplifiers—A. E. Maine. (*Electronic Eng.*, vol. 26, pp. 514–521; December, 1954.) The principle of the "half-wave" magnetic amplifier is extended to three-phase circuits. Various arrangements are described. Applications in the field of high-power control systems are discussed.

621.375.4.026 671
The Transistor as a D.C. Amplifier for use in Microwave Measurements—C. F. Davidson. (*Electronic Eng.*, vol. 26, pp. 548–549; December, 1954.) A junction-type transistor with emitter earthed may have a current amplification as high as 50, with low input impedance and high output impedance. Such an arrangement is useful for amplifying the current from a Si rectifier before application to a meter, and enables the usual galvanometer to be replaced by a robust microammeter.

621.375.5 672
Analyses of Basic Dielectric Amplifier Circuits—Shou-Hsien Chow. (*Jour. Appl. Phys.*, vol. 25, pp. 1297–1301; October, 1954.) Analysis is based on a simplified charge/voltage characteristic neglecting hysteresis; both parallel- and series-connected arrangements are studied. The steady-state response can be found with a high degree of accuracy by a method involving successive approximations; transient response is also discussed.

GENERAL PHYSICS

535.215 673
Photoelectric Emission in the Extreme Ultraviolet—H. E. Hinteregger. (*Phys. Rev.*, vol. 96, pp. 538–539; October 15, 1954.) Results of experimental studies on photoelectric emission from various metals for quantum energies up to 21.2 ev cannot even qualitatively be accounted for by the common "free-electron"—"surface effect" representation. A new theoretical model capable of explaining the observations at high photon energies is presented.

537.226:537.52 674
The Influence of the Cathode Material on Measured Breakdown Strengths of Solid and Liquid Dielectrics—J. J. O'Dwyer. (*Aust. Jour. Phys.*, vol. 7, pp. 400–409; September, 1954.)

537.311.31 675
Kinetic Equation for Electrons in Metals in Strong Fields—V. P. Shabanski. (*Zh. Eksp. Teor. Fiz.*, vol. 27, pp. 142–146; August, 1954.) *See* also 676 below.

537.311.31 676
On Deviations from Ohm's Law in Metals—V. P. Shabanski. (*Zh. Eksp. Teor. Fiz.*, vol. 27, pp. 147–155; August, 1954.) It is shown, on the basis of the kinetic equations of electrons in metals in strong fields (675 above), that the deviations observed are due primarily to the delayed transmission of energy at the collision of electrons with the lattice. At sufficiently low temperatures, the resistance should pass through a minimum at a given current.

537.52 677

On the Dependence of the Decay Times of Space Charges by the Static Characteristic in Intermittent Discharges—D. Brini, O. Rimondi and P. Veronesi. (*Nuovo Cim.*, vol. 12, pp. 413–424; September 1, 1954. In English.) The validity of the hypothesis previously formulated [2068 of 1954 (Brini and Veronesi)] has been investigated experimentally. Measured decay times depend on the external circuit associated with the discharge tube, but the existence of an inherent decay time dependent only on the static characteristic of the tube is indicated. An empirical method is developed for calculating decay times.

537.52 678

Space Charge Formation and the Townsend Mechanism of Spark Breakdown in Gases—R. W. Crowe, J. K. Bragg and V. G. Thomas. (*Phys. Rev.*, vol. 96, pp. 10–14; October 1, 1954.)

537.523.4 679

Measurement of the Current during the Formative Time Lag of Sparks in Uniform Fields in Air—H. W. Bandel. (*Phys. Rev.*, vol. 95, pp. 1117–1125; September 1, 1954.) Measurements were made of the current in a parallel plane gap during the period between application of a voltage and occurrence of breakdown. The current increased from 10^{-6} *a* a few microseconds after application of the voltage to 10^{-2} *a* just before breakdown, for time lags between 10 and 100 μs. The results are in agreement with previously developed theory, except for an observed delay in the initial current rise; a possible explanation of this is discussed.

537.525.72:537.562 680

Determination of the Electronic Temperature in U.H.F. Gas Discharges—M. Bayet and F. Guérineau. [*Compt. Rend. Acad. Sci.* (*Paris*), vol. 239, pp. 1029–1031; October 27, 1954.] Measurements made in an electrodeless discharge over a pressure range 0.13-11 mm Hg and an electron-concentration range of ratio 1 to 80 indicate that the electronic temperature remains practically constant, its value being 30,000 degrees K to within 10 per cent in dry air.

537.533:537.534.8 681

Auger Ejection of Electrons from Tungsten by Noble Gas Ions—H. D. Hagstrum. (*Phys. Rev.*, vol. 96, pp. 325–335; October 15, 1954.) Report of an experimental investigation using atomically clean tungsten and ions with various charges. The results indicate a value of about 6.3 ev for the energy of the Fermi level above the ground state in the conduction band in tungsten.

537.533:537.534.8 682

Theory of Auger Ejection of Electrons from Metals by Ions—H. D. Hagstrum. (*Phys. Rev.*, vol. 96 pp. 336–365; October 15, 1954.)

537.533.73/.74 683

Diffraction and Inelastic Scattering of Electrons [in Metals]—A. Ya. Vyatskin. (*Zh. Eksp. Teor. Fiz.*, vol. 27, pp. 162–170; August, 1954.)

537.533.8:546.45 684

Secondary Electron Emission from Thin Layers of Be: Part 1—I. M. Bronshtein and T. A. Smorodina. (*Zh. Eksp. Teor. Fiz.*, vol. 27, pp. 215–223; August 1954.) An experimental investigation is reported of the change of the secondary emission coefficient (σ) and the electron energy distribution with the adsorption of Be atoms on Ni. σ decreases monotonically with adsorption of pure Be, but increases at first with impure Be, decreasing finally to σ_{Be}. The emission depth of secondary electrons depends linearly on the energy of the primary electrons in the range 100–600 ev.

537.533.8:546.561 685

Investigation of Energy-Distribution Function of Secondary Electrons from Cu Single Crystal covered with a Single-Crystal Cu_2O Layer using the Method of Electrical Differentiation—N. B. Gornyi. (*Zh. Eksp. Teor. Fiz.*, vol. 27, pp. 171–179; August, 1954.) The subsidiary maxima observed previously (2918 of 1954) are confirmed and discussed. See also 3527 of 1954 (Gornyi and Rakhovich).

537.562:538.561 686

Dielectric Constant of Plasma in Stationary Magnetic Field—M. E. Gertsenshtein. (*Zh. Eksp. Teor. Fiz.*, vol. 27, pp. 180–188; August, 1954.) The tensor of the complex dielectric constant is calculated taking into account the thermal motion of the electrons. It is shown that in a system of coordinates connected with the moving electron, the field of a monochromatic plane electric wave is frequency modulated, hence resonance effects occur at higher harmonics. Gaps in the plasma oscillation spectrum at multiples of the gyromagnetic frequency [2151 of 1951 (Gross)] can only occur if two conditions are satisfied; the first is the condition for resonance effects to occur with all electrons the second gives the condition for high intensity of higher harmonics. With radio waves the effect of higher harmonics is negligible and hence there are no gaps in the radio wave spectrum. The conditions are satisfied in the case of sound waves in ionized gas and the effects due to resonance at multiples of the gyromagnetic frequency can be considerable.

537.581:546.56 687

Thermionic Emission from Copper at the Melting Point—V. G. Bol'shov and L. I. Dobretsov. [*Compt. Rend. Acad. Sci.* (*URSS*), vol. 98, pp. 193–196; September 11, 1954. In Russian.] An experimental determination is reported of the constants A and ψ in the Richardson-Dushman equation $j = AT^2 \exp(-\epsilon\psi/kT)$ where ϵ is the electron charge and ψ is the effective or isothermal work function. For solid Cu at the melting point the values of A and ψ were 16.7 a. cm^{-2}. deg^{-2} and 4.4 v, respectively, for liquid Cu 3.2×10^5 a. cm^{-2}. deg^{-2} and 5.5 v respectively. The discontinuity at the melting point is discussed.

538.1/.2 688

Recent Developments in Magnetism—E. P. Wohlfarth. [*Research* (*London*), vol. 7, pp. 360–367; September, 1954.] A survey with reference to 16 publications dealing with various aspects of the subject.

538.122 689

Magnetic Flux produced by a Dipole Located inside a Ferromagnetic Circular Wire—S. M. Rytov. (*Zh. Eksp. Teor. Fiz.*, vol. 27, pp. 307–312; September, 1954.) An approximate formula is derived for the magnetic flux through a coaxial plane circular area normal to the wire, due to a magnetic dipole element inside the wire. The radii of the circular area and the wire are assumed to be small compared with the axial distance between the circular area and the dipole element. For experimental confirmation of the formula see Grachev et al. (690 below).

538.122 690

Experimental Investigation of Change of Magnetic Flux in a Wire when One Domain is Remagnetized—A. A. Grachev, K. A. Goronina, N. N. Kolachevski and I. A. Andrianova. (*Zh. Eksp. Teor. Fiz.*, vol. 27, pp. 313–317; September, 1954.) The problem, which is of importance in magnetic recording, was investigated theoretically by Rytov (689 above); the calculated and experimental results are in good agreement.

538.221:538.566 691

Theory of Strong Electromagnetic Waves in Massive Iron—W. MacLean. (*Jour. Appl. Phys.*, vol. 25, pp. 1267–1270; October, 1954.) Maxwell's equations are solved for propagation in material having a rectangular hysteresis curve. Formulas are derived for depth of penetration, wave impedance and power input. The results are compared with those of Rosenberg (*Electrician*, vol. 91, p. 188; August, 1923). See also 2006 of 1954 (Papoulis).

538.566 692

Reflection from a Wire Grid Parallel to a Conducting Plane—J. R. Wait. (*Canad. Jour. Phys.*, vol. 32, pp. 571–579; September, 1954.) The parallel-wire grid backed by a conducting plane can be represented by an impedance shunted across a transmission line as in the case of a single wire [2589 of 1948 (Macfarlane)]. The value of this impedance depends on the angle of incidence, the spacing of the grid wires, and the distance between grid and backing plane. Conditions are derived for the reflection coefficient to become zero.

538.566:535.42 693

Diffraction of Electromagnetic Waves by an Aperture in a Plane Screen—R. D. Kodis. (*Jour. Appl. Phys.*, vol. 25, pp. 1342–1343; October, 1954.) Discussion of 709 of 1954 (Bekefi) and 2078 of 1954 (Crysdale).

538.566:535.42 694

The Diffraction of Waves by an Irregular Refracting Medium—E. N. Bramley. (*Proc. Roy. Soc. A*, vol. 225, pp. 515–518; September 22, 1954.) "A method is described of calculating the diffraction effects produced by a thick stratum of an irregular refracting medium. It consists of evaluating the statistics of the phase irregularities in the wave-front after traversing the medium, and treating these irregularities as having been produced by a thin phase-changing screen. For a particular statistical model of the irregularities in the medium, the result is shown to be identical with that obtained by Fejer [1730 of 1954] using a different method."

538.566:535.42:517.942.9 695

A Further Note on Dual Integral Equations and an Application to the Diffraction of Electromagnetic Waves—C. J. Tranter. (*Quart. Jour. Mech. Appl. Math.*, vol. 7, pp. 314–325; September, 1954.) A solution obtained previously (1614 of 1951) is extended to cover cases in which the order of the Bessel-function kernel is not zero. As an example, the solution is applied to a problem in the diffraction of em waves by a plane slit; Groschwitz and Hönl's discussion of the problem (2183 of 1952) is criticized. Results obtained are in agreement with those of Müller and Westpfahl (1971 of 1953).

538.632:537.525 696

Hall Effect in Positive Column—K. Takayama, T. Suzuki and T. Yabumoto. (*Phys. Rev.*, vol. 96, pp. 531–532; October 15, 1954.) Report of measurements of Hall voltage in the positive column of dc gas discharge tubes as a function of magnetic field, tube current, distance between probes and gas pressure.

538.632:538.221 697

Theory of Hall Effect in Ferromagnetics—N. S. Akulov and A. V. Cheremushkina. [*Compt. Rend. Acad. Sci.* (*URSS*), vol. 98, pp. 35–38; September 1, 1954. In Russian] Assuming *s-d*-phonon interaction, the Hall voltage is given by the equation $e = [a_0\rho_0 + a_2(\rho_T - \rho_0)]I_s i$, where a_0 and a_2 are constants, ρ_0 and ρ_T are the resistances of the specimen at absolute zero and at temperature T, respectively, I_s is the intensity of magnetization at saturation and i is the current density. Comparison with experimental results obtained from measurements on a bar-shaped 45 per cent-Ni/55 per cent-Fe specimen (containing stated impurities) shows close agreement.

538.632:538.221 698

Hall Effect in Ferromagnetics—R. Karplus and J. M. Luttinger. (*Phys. Rev.*, vol. 95, pp. 1154–1160; September 1, 1954.) Anomalous effects are explained in terms of the spin-orbit interaction of polarized conduction electrons.

548.0:53 699

Wave Functions for Impurity Levels—G. F. Koster and J. C. Slater. (*Phys. Rev.*, vol. 95, pp. 1167–1176; September 1, 1954.) A general method of solving difference equations arising in impurity calculations is developed.

GEOPHYSICAL AND EXTRATERRESTRIAL PHENOMENA

523.16+621.396.11+621.396.9 700

Propagation of Electromagnetic Waves, Radio Location and Radio Astronomy—E. Roessler. (*Elektrotech. Z., Edn A*, vol. 75, pp. 632–635; September 11, 1954.) A brief survey of recent progress, particularly since 1951. 73 references.

523.16 701

Detection of Discrete Radio Sources at 21 cm Wavelength—J. P. Hagen, E. F. McClain and N. Hepburn. (PROC. I.R.E., vol. 42, p. 1811; December, 1954.) Details are tabulated of 20 sources observed at the U.S. Naval Research Laboratory. The equipment used is briefly described.

523.16 702

Nature of Discrete Sources of Cosmic R.F. Radiation—I. S. Shklovski. [*Compt. Rend. Acad. Sci.* (*URSS*), vol. 98, pp. 353–356; September 21, 1954. In Russian.] Energy considerations of the colliding gas "coronas" in Cygnus A show that a considerable proportion of the kinetic energy of the colliding masses is transferred to a relatively small number of relativistic particles and hence into rf radiation. The cut-off frequency is estimated to be about 2×10^{10} cps assuming the particles to be electrons.

523.16 703

Observations of Cosmic Noise at 9.15 mc—C. S. Higgins and C. A. Shain. (*Aust. Jour. Phys.*, pp. 460–470; September, 1954.) "From observations made at a frequency of 9.15 mc, with an aerial of beam width 29 degrees between half-power points and directed to Dec. −32 degrees, a curve of equivalent aerial temperature, as a function of sidereal time, is derived. The temperatures observed were of the order of 10^6 degrees K. The curve is compared with curves derived for similar conditions by calculation from the results of observations at 18.3 mc and at 100 mc. It is found that the equivalent temperatures increase rapidly with decreasing frequency, but the ratio of maximum to minimum temperature decreases with frequency. It is shown that 'atmospheric' noise levels observed by the standard techniques sometimes contain a large contribution from cosmic noise at this frequency."

523.72:621.396.822 704

Harmonics in the Spectra of Solar Radio Disturbances—J. P. Wild, J. D. Murray and W. C. Rowe. (*Aust. Jour. Phys.*, vol. 7, pp. 439–459; September, 1954.) Detailed account of observations reported previously (391 of 1954). Investigations over the frequency range 40–240 mc indicate that spectral features of solar noise bursts are commonly duplicated at or below the frequency of the second harmonic. The results are consistent with the hypothesis that the fundamental frequency corresponds to the natural plasma frequency of the corona in the vicinity of the source. By applying this result to a standard model of the corona, information is deduced regarding the position, velocity and size of the sources. Velocities of 500 and 4,000 km were found for two long-duration outbursts, and velocities as great as 10^5 km for short-lived type-III bursts. The generation of bursts may be associated with longitudinal plasma oscillations excited by fast streams of charged particles.

523.746:621.396.822 705

The Emission Polar Diagram of the Radio-Frequency Radiation from Sunspots—K. E. Machin and P. A. O'Brien. (*Phil. Mag.*, vol. 45, pp. 973–979; September, 1954.) The variation in received sunspot radiation with solar rotation was determined from a statistical analysis of observations made over a number of years. Half-power widths of the radiation pattern of an average sunspot, derived from this analysis, are 15 degrees, 20 degrees and 36 degrees for frequencies of 81.5, 175 and 500 mc respectively. Results indicate that the lifetime of the radiation sources is shorter for the lower frequencies; the lifetime at 175 mc is comparable with that of a visible spot.

551.510.535 706

Abnormal Amplitude of Seasonal Effects in the Ionosphere at the Equator, and Structure of the Upper Atmosphere—F. Delobeau and R. Gallet. [*Compt. Rend. Acad. Sci.* (*Paris*), vol. 239, pp. 1067–1069; October 27, 1954.] *D*-layer absorption, maximum ionization and structure of the F_2 layer have been studied. Seasonal variations observed in equatorial regions are much greater than expected from the geometrical variation of the sun's position. Known theories assume simple variation of ionosphere parameters with cos χ. The deviations observed are interpreted as indicating seasonal variations of the structure of the upper atmosphere, particularly as regards temperature and its gradient, molecular dissociation and movements of air masses. At an equatorial station at the solstices, not only is the solar radiation incident at an angle of 23 degrees, but the structure of the upper atmosphere is that appropriate to a latitude of about 23 degrees.

551.510.535 707

Motion of a Single Cloud in the Ionosphere—S. N. Mitra. (*Indian Jour. Phys.*, vol. 27, pp. 562–564; November, 1953.) The system comprising cloud and ionosphere is treated as analogous to the system formed by a horizontal wire antenna and the ground. The radiation pattern consists of minor lobes arranged symmetrically with respect to a central major lobe; as this pattern moves with the cloud, periodic fading of transmitted pulses is observed at the receiver. Periodic fading preceded and followed by a steady signal can thus, with appropriate reservations, be interpreted as due to a single cloud. An example is discussed in which 14 maxima were observed; the wavelength being 75 m, the horizontal length of the cloud is estimated to be about 1 km.

551.510.535 708

A Monochromatically Ionized Layer in a Non-Uniformly Recombinant Atmosphere; with Applications to the *D* and *E* Ionospheric Regions—S. Chapman. (*Proc. Phys. Soc.*, vol. 67, pp. 717–727; September 1, 1954.) The recombinance α of the atmosphere is assumed to be given by a term α_0 independent of height together with a term $\alpha_1 e^{-bh}$ which varies exponentially with height. A recombinance datum level is defined as that at which the two terms are equal, and heights are measured from this level, in scale-height units. "The level of the absorption peak being z_χ (when the sun's zenith distance is χ, or z_0 when $\chi=0$), the level z_m of the electron peak and the height distribution of the electron density n_e are considered, for different values of z_0 and of $c(=b/H)$, particularly $c=1$, 2, 3. When $c>0$ the electron peak is always above the absorption peak, and for $c\geqq2$ it is always above the recombinance datum level: the electron peak for $c=1$, when the absorption peak is below the recombinance datum level, is about half way between the two. The decrease of n_e (from its maximum value n_{em}) on the underside (or incline) of the electron layer can be much less steep than for a Chapman layer, if the absorption peak is below the recombinance datum level. The results for the model atmospheres considered are tentatively discussed with reference to the *E* and *D* ionospheric regions, but their potential value may be realized only when better data for the *D* region become available."

551.510.535:538.566 709

Focusing Phenomena due to Undulations of the Ionosphere, and Determination of Collision Number—Rawer and Argence. (*See* 842.)

551.510.535:551.594.5 710

Electron Density in the E-Layer during Auroral Displays deduced from Measurements of Absolute Brightness of the Auroral Luminosity—A. Omholt. (*Jour. Atmos. Terr. Phys.*, vol. 5, pp. 243–244; September, 1954.) Values of electron density calculated from the photon emission for different auroral forms range from 1.6×10^6 to 12×10^6 electrons/cm³. *See* also 716 below (Seaton).

551.510.535:551.594.5 711

The Association of Pulsating and Flaming Auroras with Complete Ionospheric Absorption at Macquarie Island—G. Major. (*Aust. Jour. Phys.*, vol. 7, pp. 471–476; September, 1954.) Simultaneous records show that pulsating or flaming auroras are frequently accompanied by complete absorption of waves incident vertically on the ionosphere, but the nocturnal variations of frequency of occurrence of the two phenomena are markedly different in form.

551.510.535:621.3.087.4 712

Equipment for Accurate Measurement of Height of Ionosphere Layers—S. J. Bauer. (*Öst. Z. Telegr. Teleph. Funk Fernsehtech.*, vol. 8, pp. 122–125; September/October, 1954.) Use of a 200-μs timebase, corresponding to a height range of 30 km, enables measurements to be made accurate to within 1 km. The timebase triggering is controlled by means of a phase shifter calibrated in height, so that any desired height range can be selected for close examination. Because of the pulse widening involved, a differentiator stage with wide-band amplifier is interposed between receiver output and indicator. Measurement procedure is described.

551.510.535:621.3.087.4 713

Ionospheric Height Measurement by the Method of Delayed Coincidence—H. Rakshit and S. D. Chatterjee. (*Naturwiss.*, vol. 41, pp. 401–402; September, 1954. In English.) An outline description, with block diagram, is given of equipment in use at an Indian station for regular observation of lunar tides in the upper atmosphere. The apparatus can be readily adapted for automatic recording of $h't$ curves. The method is basically as described previously (*Science and Culture*, vol. 17, p. 520; 1952), but the technique has been improved, giving an accuracy within ±0.1 km. Good results are obtained even in the presence of heavy atmospherics.

551.510.535:621.396.812.3.029.53 714

Periodic Fading of Medium-Wave Radio Signals—B. R. Rao and N. V. G. Sarma. (*Current Sci.*, vol. 23, pp. 287–288; September, 1954.) Slow fading was found to correspond to interference between $1\times E$ and $2\times E$ paths and between $2\times E$ and $3\times E$ paths, rapid fading to interference between $1\times E$ and $3\times E$ paths. The values of the vertical drift velocity of the *E* layer calculated on the basis of observations of the three types of interference at an Indian station, for the period between 0700 and 0800 hours, were 2.15 m, 2.34 m, and 2.29 m respectively. Ground-wave fading indicates a drift velocity of 2.37 m. Analysis of records shows that the drift velocity decreases during the morning; depth of fading also decreases, due to increasing *D*-layer absorption.

551.594.5 715

Variations of Intensity of the Aurora at Macquarie Island—F. Jacka. (*Aust. Jour. Phys.*, vol. 7, pp. 477–484; September, 1954.)

551.594.5 716

Excitation Processes in the Aurora and Air-

glow: Part 1—Absolute Intensities, Relative Ultraviolet Intensities and Electron Densities in High-Latitude Aurorae. Part 2—Excitation of Forbidden Atomic Lines in High-Latitude Auroras—M. J. Seaton. (*Jour. Atmos. Terr. Phys.*, vol. 4, pp. 285–313; January, 1954.) The excitation processes are evaluated on the basis of optical and rf observations. Calculations show that electron densities of 10^7–10^8 cm^{-3} occur in bright high-latitude auroras. A summary is given of the various excitation and deactivation processes which may occur and an attempt is made to decide which of those will be of major importance.

551.594.6 717
Atmospherics with Long Trains of Pulses—F. Hepburn and E. T. Pierce. (*Phil. Mag.*, vol. 45, pp. 917–932; September, 1954.) "The waveforms of atmospherics having long-continued trains of pulses and the systematic modifications associated with time of recording, storm distance and the presence of a low-frequency component, are described. Their interpretation is discussed and the results of analysis —assuming the simple ionospheric reflection mechanism—are presented. Estimates of reflection height and storm distance show the applicability of the theory to the temporal parameters of the waveforms, and the origins of two groups of atmospherics having calculated ranges of 4500 and 7000 km are considered. The variation of pulse amplitude with reflection order is shown to lead to the postulation of horizontal radiating elements in the channel during the later stages of the return stroke, although difficulties arise in reconciling this concept with considerations of the magnitude and orientation of the horizontal elements." *See* also 2771 of 1953.

LOCATION AND AIDS TO NAVIGATION

621.396.9+621.396.11+523.16 718
Propagation of Electromagnetic Waves, Radio Location and Radio Astronomy—E. Roessler. (*Elektrotech. Z., Edn. A*, vol. 75, pp. 632–635; September 11, 1954.) A brief survey of recent progress, particularly since 1951. 73 references.

621.396.96.012.3 719
Radar Doppler Nomograph—A. H. Schooley. (*Electronics*, vol. 27, p. 180; December, 1954.) A nomogram is presented relating the Doppler frequency shift to transmitter frequency and target velocity.

621.396.963.325 720
P.P.I. Light-Spot Brightness Probability Distributions—G. C. Sponsler and F. L. Shader. (*Jour. Appl. Phys.*, vol. 25, pp. 1271–1277; October, 1954.) A study is made using the statistics of noise theory. For a Type-10KP7 cathode-ray tube, the intensifier electrode has an approximately 2.5-power-law characteristic; this combines with the square-law second detector to give an over-all 5th-power detection characteristic. The spot brightness is investigated for integration of seven individual returns. "Various mathematical methods of handling the problem are considered. The Edgeworth series approximation is found to give poor results compared with the Laguerre polynomial approximation. By the latter method the light brightness probabilities are found to be obtainable by interpolation from a table of the incomplete gamma function. Ancillary tables of statistical moments and selected values of the confluent hypergeometric function, ${}_1F_1(-5n/2;\ 1;\ -x)$, are included in the text."

621.396.969:551.577/.578 721
Radar Echoes from Monsoon Rain—L. S. Mathur, A. C. De, B. N. Dutta and H. Mitra. (*Indian Jour. Met. Geophys.*, vol. 5, pp. 173–186; April, 1954.) Account of observations made at New Delhi, using modified Type-AN/APQ-13 3-cm radar equipment. PPI displays corresponding to different weather conditions are reproduced.

621.396.969.33/.34:621.396.822 722
The Reduced Range in a Radar Subjected to an External Noise Generator—U. Tiberio. (PROC. I.R.E., vol. 42, pp. 1791–1798; December, 1954.) An analytical method is described for calculating the reduction of range due to a noise generator (a) carried by the target, or (b) at some fixed location. A "reduced range index" is determined from consideration of free-space operation against aircraft, and the effect of reflection from the sea is investigated in relation to operation at low height against ships. The effect of noise on the visibility factor is briefly discussed.

MATERIALS AND SUBSIDIARY TECHNIQUES

535.5 723
Ion Pump—P. F. Váradi. (*Acta Tech. Acad. Sci. Hungaricae*, vol. 9, pp. 343–353; 1954. In English.) The ultimate pressure and pumping speed calculated for the case of a simple model are in agreement with experimental results of Foster et al. (*Rev. Sci. Instr.*, vol. 24, pp. 387–390; May, 1953.), who described an ion pump with pumping speeds between 3,000 and 7,000 l/sec at a base pressure of about 10^{-6} mm Hg. The present experimental result indicates that the reduction of gas pressure is attributable not solely to adsorption but also to a true pumping effect.

535.215:[537.311.33+537.226 724
Photoeffect from Surface Levels—G. E. Pikus. (*Zh. Eksp. Teor. Fiz.*, vol. 27, pp. 369–381; September, 1954.) The external photoeffect in semi-conductors and dielectrics, corresponding to removal of electrons from the surface zone, is considered theoretically. Expressions are derived for the energy distribution of the emitted photoelectrons and the quantum output and its dependence on the frequency of the incident light.

535.215:546.482.21 725
Photovoltaic Effect in Cadmium Sulfide—D. C. Reynolds, G. Leies, L. L. Antes and R. E. Marburger. (*Phys. Rev.*, vol. 96, pp. 533–534; October 15, 1954.) Brief report of observations.

535.215:546.482.21 726
Absorption and Conductivity Measurements on CdS in the Soft-X-Ray Region—E. Schnürer. [*Ann. Phys.*, (*Lpz.*), vol. 15, pp. 15–20; September 15, 1954.]

535.215:546.817.241:539.23 727
Effect of Oxygen on the Electrical Properties of Lead Telluride Films—D. E. Bode and H. Levinstein. (*Phys. Rev.*, vol. 96, pp. 259–265; October 15, 1954.) Account of an experimental investigation. Exposure to oxygen produces first an increase and then a decrease in the film resistance. The nature of the material changes from *n*-type to *p*-type in the neighborhood of the resistance maximum. The magnitudes of the photoconductive and photovoltaic effects depend on the amount of oxygen adsorbed. The observed results are explained on the basis of a model in which the oxygen removes electrons first from the conduction band, then from trapping states, and finally from the valence band.

535.37 728
On the Infrared-Sensitive Behaviors of Some Doubly Activated ZnS Phosphors—S. Asano. (*Jour. Phys. Soc.* (*Japan*), vol. 9, pp. 580–594; July/August, 1954.)

535.37 729
Investigations of the Stimulation of Phosphorescence in Calcium Oxide—A. Crozet and J. Janin. [*Compt. Rend. Acad. Sci.* (*Paris*), vol. 239, pp. 1031–1034; October 27, 1954.] The effect of different activators is discussed. If rare earths are used there is a large recapture of liberated electrons.

537.226.2 730
The Dielectric Behaviour of Acetaldehyde Vapour at 9000 Mc/s—Krishnaji and P. Swarup. (*Z. Phys.*, vol. 138, pp. 550–556; September 18, 1954. In English.)

537.226.31 731
Investigation of Dielectric Losses due to Low-Frequency Relaxation in Polyethylene—G. P. Mikhailov, A. M. Lobanov and B. I. Sazhin. (*Zh. Tekh. Fiz.*, vol. 24, pp. 1553–1560; September, 1954.) Experimental results show that the losses are connected with the presence of $C=0$ polar groups and their orientation. The relaxation time associated with lf ($\sim 10^2$ cps) losses decreases with extension of the specimen, that of hf ($\sim 10^9$ cps) losses increases. The dependence of the loss angle on temperature, frequency, and percentage of crystalline phase is shown graphically.

537.226.33 732
Transient State in Dielectrics—J. Granier and P. Caillon. [*Compt. Rend. Acad. Sci.* (*Paris*), vol. 239, pp. 1025–1027; October 27, 1954.] If only one hysteresis effect came into play, it would be possible to predict ac dielectric properties from dc properties. Examination of experimental results on high polymers confirms the existence of two independent hysteresis phenomena, the one related to the dipole orientation and the other to ionic polarization. *See* also 2963 of 1954.

537.227:546.431.824-31 733
Electromechanical Activity of $BaTiO_3$ Ceramic subjected to Opposing Polarization—T. F. Hueter and D. P. Neuhaus. (*Naturwiss.*, vol. 41, p. 424; September, 1954.) Over a range of field strength within the coercive field strength, second-harmonic oscillations become pronounced while the fundamental and the third harmonic disappear. Curves showing the variation of fundamental and second-harmonic amplitude with field strength are presented for a disk of thickness 0.1 cm, and an interpretation is provided in terms of domain processes.

537.227:546.431.824-31 734
An Experimental Study of Polarization Effects in Barium Titanate Ceramics—T. F. Hueter, D. P. Neuhaus and J. Kolb. (*Jour. Acous. Soc. Amer.*, vol. 26, pp. 696–703; September, 1954.) The following points were investigated: (a) transducer performance as a function of polarizing bias; (b) relative role of mechanical and dielectric losses; (c) coercivity of pre-polarized $BaTiO_3$; (d) effect of bias on subsidiary transducer responses; (e) constriction of dielectric hysteresis loops. The value of the experiments for elucidating the relation between the properties of the ceramic and single-crystal forms of the material is discussed.

537.227:546.431.824-31 735
Dielectric-Constant Behavior of Single-Domain, Single Crystals of Barium Titanate in the Vicinity of the Curie Point—M. E. Drougard and D. R. Young. (*Phys. Rev.*, vol. 95, pp. 1152–1153; September 1, 1954.) Brief report of measurements which confirm earlier observations by Cross (751 of 1954) of a discontinuity in the value of the dielectric constant at the Curie point.

537.227:546.431.824.831.4-31 736
Ferroelectric Properties of Solid Solutions of Barium Zirconate in Barium Titanate—G. A. Smolenski, N. P. Tarutin and N. P. Grudtsin. (*Zh. Tekh. Fiz.*, vol. 24, pp. 1584–1593; September, 1954.) An experimental investigation of solutions containing up to 40 per cent (molar) of $BaZrO_3$. Results, which are presented graphically, show (a) the highest value of dielectric constant (>12,000) at a frequency of 1 kc occurs for 18–20 per cent $BaZrO_3$ content,

(b) the Curie temperature is displaced downwards more slowly than in the $BaSnO_3$-in-$BaTiO_3$ solutions due to the different character of the bonds of Zr and Sn ions with oxygen ions, (c) the dielectric constant of solutions with low electrostriction falls considerably following polarization at high field strengths, (d) the dependence of resonance frequencies on field strength decreases with increase of the zirconate content, and (e) the piezoelectric-modulus maximum occurs at a temperature slightly lower than that corresponding to the dielectric-constant maximum. Some properties of pure $BaTiO_3$ were also investigated.

537.311.31:[538.632+537.312.8 737

Hall Effect and Change of Resistance of Pb, Cu, and Mg in a Magnetic Field—E. S. Borovik. (*Zh. Eksp. Teor. Fiz.*, vol. 27, pp. 355–368; September, 1954.) An experimental investigation is reported on pure polycrystalline specimens in fields of strengths up to about 25,000 oersted at temperatures between 2 degrees and 300 degrees K. From a comparison of the experimental results with results calculated on the basis of an isotropic model of a metal with overlapping energy bands values are obtained for the mobilities and concentrations of charge carriers. The magnitude of the mean free path is compared with the values obtained by other methods. Results are tabulated and presented graphically.

537.311.31:621.3.029.64 738

Surface Loss of Silver-Plated Metal Plates at 9000 Mc/s and its Correlation with Surface Roughness—S. Saito. (PROC. I.R.E., vol. 42, p. 1810; December, 1954.) A cavity-resonator method is outlined for comparing the surface loss of metal plates. The surface roughness was simultaneously observed by a mechanical-stylus method and by means of electron micrographs. The results confirm that surface loss increases rapidly with increase in surface roughness. Plating defects in the silver-plated samples appear to be responsible for abnormally high losses.

537.311.33 739

Magnetoresistance Effect in Cubic Semiconductors with Spheroidal Energy Surfaces—M. Shibuya. (*Phys. Rev.*, vol. 95, pp. 1385–1393; September 15, 1954.) "The collision frequency of electrons having a spheroidal energy surface with acoustical modes of vibration is calculated without neglecting phonon energy. Using an asymptotic form in which the collision frequency is proportional to the square root of their energy, the electronic current in a semiconductor in combined magnetic and weak electric fields can be calculated in a closed form by the formal theory of conductivity. The results are compared with those obtained experimentally by Pearson and Suhl (166 of 1952)."

537.311.33 740

Mathematical Methods for Zone-Melting Processes—H. Reiss. [*Jour. Metals (New York)*, vol. 6, pp. 1053–1059; September, 1954.] The mechanism of zone melting [2125 of 1954 (Pfann)] is discussed in terms of a transport process including diffusive and convective flows. This approach provides a basis on which equations are developed for the solute concentration in the ingot as a function of the number of zone passes.

537.311.33 741

Quantum Theory of Cyclotron Resonance in Semiconductors—W. Kohn and J. M. Luttinger. (*Phys. Rev.*, vol. 96, pp. 529–530; October 15, 1954.) For the electrons in semiconductors, the quantum theory is identical with the classical theory [2479 of 1950 (Shockley)]. For holes, the situation is complicated due to degeneracy at the top of the valence band; the quantum theory leads to different energy levels and selection rules for low quantum numbers, but for high quantum numbers the classical theory is again valid.

537.311.33:537.323 742

Temperature Dependence of Thermoelectric Power of Impurity Semiconductors—T. A. Kontorova. (*Zh. Tekh. Fiz.*, vol. 24, pp. 1687–1696; September, 1954.) Theoretical considerations show that the large values of the thermoelectric power observed by Frederikse (1093 of 1954) and others at very low temperatures can be accounted for by accepted theory, assuming the electron gas to be highly degenerate in that region. The maximum occurs at the transition from the degenerate state to the "classical" state.

537.311.33:537.323:546.289 743

Theory of Thermoelectric Power in Semiconductors—J. Tauc. (*Phys. Rev.*, vol. 95, p. 1394; September 15, 1954.) A method is suggested for calculating the thermoelectric power which gives a more correct expression than that presented by Johnson and Lark-Horowitz (1092 of 1954).

537.311.33:546.23 744

Some Investigations on the Electrical Properties of Hexagonal Selenium—L. M. Nijland. (*Philips Res. Rep.*, vol. 9, pp. 259–294; August, 1954.) Known properties of Se are reviewed with references to published data. A method of purifying 99.9 per cent-pure Se by evaporation at a temperature near its melting point is described. Results of measurements of hf conductivity confirm the assumption that polycrystalline Se consists of crystals of fairly good conductivity embedded in poorly conducting layers of amorphous Se. The inclusion of thallium increases the resistance of the layers without greatly affecting that of the crystals. Measurements of Hall effect and of equivalent shunt resistance as a function of frequency are also reported for pure and bromine-containing samples; results indicate the same layer structure, but inclusion of Br lowers the resistance of the layers. Conduction mechanism is discussed with reference to detailed experimental results.

537.311.33:[546.28+546.289 745

Etch Pits and Dislocations in Germanium and Silicon—J. J. Oberly. [*Jour. Metals (New York)*, vol. 6, pp. 1025–1026; September, 1954.] Brief illustrated discussion of conical etch pits observed while examining lineage boundaries described by Vogel et al. (2693 of 1953).

537.311.33:[546.28+546.289 746

Theory of Electron Multiplication in Silicon and Germanium—P. A. Wolff. (*Phys. Rev.*, vol. 95, pp. 1415–1420; September 15, 1954.) Multiplication of electrons and holes at junctions in Si and Ge is explained in terms similar to those of gas-discharge theory. The calculated ionization-rate/field characteristic for Si is in agreement with that obtained experimentally, assuming a mean free path of 200 Å for interactions between electrons and optical phonons.

537.311.33:[546.28+546.289 747

Mobility of Impurity Ions in Germanium and Silicon—C. S. Fuller and J. C. Severiens. (*Phys. Rev.*, vol. 96, pp. 21–24; October 1, 1954.) The diffusivity D of Li in Ge and Si was investigated by measuring the mobilities of the Li^+ ions on applying an electric field. Using the Einstein formula relating the two properties, the value of D was found to be 25×10^{-4} exp $(-11,800/RT)$ for Ge and 23×10^{-4} exp $(-15,200/RT)$ for Si, in satisfactory agreement with previously published results. The region into which the Li diffuses in the p-type Ge changes to n-type, but a small region round the injection area reverts to p-type. Similar experiments with Cu in n-type Ge are mentioned.

537.311.33:[546.28+546.289]:536.2 748

The Thermal Conductivity of Germanium and Silicon at Low Temperatures—H. M. Rosenberg. (*Proc. Phys. Soc.*, vol. 67, pp. 837–840; September 1, 1954.) "The thermal conductivity of a single crystal of Ge and a polycrystalline specimen of Si have been measured in the range 2 to 100 degrees K. Both specimens were very pure. The results indicate that, at low temperatures at least, the lattice waves are not scattered by the conduction electrons, but that their mean free path is limited either by the size of the specimen (for the germanium) or by the crystallite size (for the silicon)."

537.311.33:546.28 749

Electron Spin Resonance of an Impurity Level in Silicon—A. Honig and A. F. Kip. (*Phys. Rev.*, vol. 95, pp. 1686–1687; September 15, 1954.) Electron spin resonance has been observed in a Si sample containing Li at a concentration of 7×10^{16} atoms/cm^3. The ionization energy of an electron in the impurity level is 0.033 ev. A single resonance line was observed over the temperature range 4 degrees–20 degrees K using an applied frequency of about 8.8 kmc and a magnetic field of about 3,200 oersted; the same line was observed at 300 mc. The evidence indicates that the electron is bound to the impurity atom rather than associated with an impurity band.

537.311.33:546.28 750

Electrical Properties of Silicon containing Arsenic and Boron—F. J. Morin and J. P. Maita. (*Phys. Rev.*, vol. 96, pp. 28–35; October 1, 1954.) Measurements were made of the conductivity and Hall constant of single-crystal specimens over the temperature range 10 degrees–1,100 degrees K. Analysis of the extrinsic carrier concentration values, as computed from the Hall constant, indicates the ionization energy of As donor levels to be 0.049 ev, and of B acceptor levels to be 0.045 ev for low impurity concentrations. Fermi degeneracy is found to occur in the impurity concentration range 10^{18}–10^{19} per cm^3. A formula is derived for the variation of carrier concentration with temperature up to 700 degrees. Mobility values are computed.

537.311.33:546.28 751

Effective Masses of Holes in Silicon—R. N. Dexter and B. Lax. (*Phys. Rev.*, vol. 96, pp. 223–224; October 1, 1954.) Cyclotron-resonance experiments are reported, the carriers being excited by infrared radiation chopped at 900 cps. The effective mass of holes is plotted as a function of direction of magnetic field.

537.311.33:546.28 752

Effective Masses of Electrons in Silicon—R. N. Dexter, B. Lax, A. F. Kip and G. Dresselhaus. (*Phys. Rev.*, vol. 96, pp. 222–223; October 1, 1954.) Results of cyclotron resonance experiments using optical excitation of carriers are reported. Curves are shown of the effective electron mass as a function of direction of magnetic field.

537.311.33:546.28 753

Polarization of Arsenic Nuclei in a Silicon Semiconductor—A. Honig. (*Phys. Rev.*, vol. 96, pp. 234–235; October 1, 1954.) A mechanism capable of producing nearly 100 per cent polarization of nuclear spins at moderate values of field strength and temperature has been found in the course of electron spin resonance studies of the type previously reported [3254 of 1954 (Fletcher et al.)].

537.311.33:546.289 754

Electron Multiplication in Germanium at Low Temperature—E. J. Ryder, I. M. Ross and D. A. Kleinman. (*Phys. Rev.*, vol. 95, pp. 1342–1343; September 1, 1954.) In response to Conwell's suggestion of an experimental check (2976 of 1954), measurements were made of the current density in a small bar of n-type Ge as

a function of electric field strength at several temperatures in the range 12.1 degrees–300 degrees K. The curves for the lower temperatures exhibit a steep rise over part of the field-strength range; this is interpreted as evidence of electron multiplication.

537.311.33:546.289 755
Distribution of the Mass Transported from a Collector into a Germanium Crystal by the Forming Process—W. M. Aarons, M. Pobereskin, J. E. Gates and E. B. Dale. (*Phys. Rev.*, vol. 95, p. 1345; September 1, 1954.) Measurements were made using a radioactive isotope of Au as tracer. The Au was plated on a *W* needle which was used to form the crystals. Results obtained with successive lappings of the surface indicate that the concentration of the transferred Au atoms is high in a region near the surface, then falls, rises a little, and finally drops abruptly.

537.311.33:546.289 756
The Interaction of Impurity Atoms with Dislocations in Germanium—A. D. Kurtz and S. A. Kulin. (*Acta metallurgica*, vol. 2, pp. 352–354; March, 1954.) It is suggested that the existence of dislocations in Ge gives rise to certain specific distributions of solute atoms. Results of approximate calculations give some support to this view; the theory enables some of the electrical properties of Ge to be predicted.

537.311.33:546.289 757
Effect of Dislocations on Minority-Carrier Lifetime in Germanium—S. S. Kulin and A. D. Kurtz. (*Acta metallurgica*, vol. 2, pp. 354–356; March, 1954.) The density of randomly distributed dislocations in Ge, as determined by two independent methods, varies between 10^6 and 10^8 per cm^2. The lifetime of minority carriers decreases hyperbolically as the dislocation density increases. The recombination efficiency per dislocation is about 2×10^{-3} per cm per second. The change in energy gap width is calculated as a function of position in relation to a dislocation.

537.311.33:546.289 758
New Minority-Carrier Phenomenon in Germanium—S. J. Angello and T. E. Ebert. (*Phys. Rev.*, vol. 96, pp. 221–222; October 1, 1954.) An experiment is described in which minority carriers were withdrawn from a bar of *n*-type Ge at an In-alloyed junction biased in the high-resistance direction, and the deficit was propagated along the bar by means of an electric field. The effect is the inverse of that described by Haynes and Shockley (2109 of 1949).

537.311.33:546.289 759
Injection Breakdown in Iron-Doped Germanium Diodes—W. W. Tyler. (*Phys. Rev.*, vol. 96, pp. 226–227; October 1, 1954.) Brief description of an experiment providing evidence of hole traps in high-resistivity *n*-type Fe-doped Ge.

537.311.33:546.289 760
Properties of Zinc-, Copper-, and Platinum-Doped Germanium—W. C. Dunlap, Jr. (*Phys. Rev.*, vol. 96, pp. 40–45; October 1, 1954.) Measurements of Hall constant and resistivity over the temperature range 15 degrees–400 degrees K indicate that Zn, Cu and Pt are all acceptors, with ionization energies of 0.029, 0.036 and 0.040 ev respectively. The temperature variation observed could be due to (a) surface conductivity with low activation energy, (b) traces of low-ionization-energy acceptors, or (c) internal leakage due to imperfections or dislocations. Evidence was found of a Pt acceptor level 0.2 ev below the conduction band and of a Cu acceptor level just below the middle of the forbidden band.

537.311.33:546.289 761
Thermal Effects on Lifetime of Minority Carriers in Germanium—R. A. Logan and M. Schwartz. (*Phys. Rev.*, vol. 96, p. 46; October 1, 1954.) Practical precautions are described which enable Ge to be heated to temperatures as high as 875 degrees C. without causing a decrease in the lifetime of the minority carriers.

537.311.33:546.289 762
Precision Wavelength and Isotopic Shift Measurements of Germanium Arc Lines—G. V. Deverall, K. W. Meissner and G. J. Zissis. (*Phys. Rev.*, vol. 95, pp. 1463–1468; September 15, 1954.)

537.311.33:546.623.86 763
Some Electrical Properties of AlSb—W. Sasaki, N. Sakamoto and M. Kuno. (*Jour. Phys. Soc. Japan*, vol. 9, p. 650; July/August, 1954.) Measurements of resistivity, Hall constant and thermoelectric power as a function of temperature are reported.

537.311.33:[546.682.86+546.682.19 764
Anomalous Optical Behavior of InSb and InAs—H. J. Hrostowski, G. H. Wheatley and W. F. Flood, Jr. (*Phys. Rev.*, vol. 95, pp. 1683–1684; September 15, 1954.) Observations have been made of the room-temperature transmission spectra of degenerate *n*-type InSb samples doped so as to have different values of electron concentration. The absorption edge is displaced to shorter wavelengths as the electron concentration is increased. The variation of the energy gap E_0 with electron concentration is compared with the curve obtained by calculation from the data of Tannenbaum and Maita (758 of 1954). Similar but smaller effects have been observed with InAs. The results indicate that the anomalous variation of E_0 is unlikely to be due to a specific impurity.

537.311.33:546.682.86 765
Neutron Irradiation of Indium Antimonide—J. W. Cleland and J. H. Crawford, Jr. (*Phys. Rev.*, vol. 95, pp. 1177–1182; September 1, 1954.) Measurements were made of Hall coefficient and resistivity of *n*-type and *p*-type single crystals of InSb after exposure to neutron irradiation. The results indicate that bombardment by fast neutrons converts *p*-type material to *n*-type and produces shallow electron traps in *n*-type material. Reduction of carrier mobility and changes of carrier concentration resulting from the bombardment can be removed by heat treatment.

537.311.33:546.817.241 766
Preparation and Properties of Lead Telluride—E. L. Brady. (*Jour. Electrochem. Soc.*, vol. 101, pp. 466–473; September, 1954.) "Single crystals of lead telluride, PbTe, have been prepared and their resistivity and Hall coefficients determined. Both *n*- and *p*-type lead telluride have been produced, but they were not of high resistivity. Charge carrier concentration in every case has been $1-5\times10^{18}/\text{cm}^3$. Hall mobility of *n*- and *p*-type carriers was found to be about 2,240 and 860 cm^2/volt-sec, respectively. Material of *p*-type was converted to *n*-type by allowing lead to diffuse into the crystal at 500 degrees C. The value of the diffusion coefficient of Pb in PbTe at this temperature is estimated to lie between 5.6×10^{-8} and 9.2×10^{-8} cm^2/sec."

537.311.33:546.817.241:539.234:535.3 767
Optical Properties of Lead Telluride—M. E. Lasser and H. Levinstein. (*Phys. Rev.*, vol. 96, pp. 47–52; October 1, 1954.) Evaporated films were prepared having a density about 10 per cent less than that of the bulk material. The optical constants were calculated from curves of reflection and transmission plotted against λ. Addition of oxygen caused an increase in absorption and a slight increase in refractive index; the optical properties were then strongly dependent on the film temperature. A possible explanation of the results is presented.

537.311.33:621.314.63 768
Influence of Recombination at Contact on the Volt/Ampère Characteristics of a Rectifier—A. V. Rzhanov. [*Compt. Rend. Acad. Sci.* (*URSS*), vol. 98, pp. 389–390; September 21, 1954. In Russian.] An expression is derived for the current flowing in an *n*-type semiconductor bounded on one side by *p*-type material and on the other by a nonactive contact. The electron flow across the *p-n* junction is neglected. Surface recombination takes place at the other boundary. If the thickness of the semiconductor is small compared with the diffusion path of holes, and the velocity of surface recombination is large, then the effect of recombination is to increase the saturation current. This result is derived on the assumption of a concentration of holes which is small in comparison with the equilibrium concentration of electrons, i.e. applies to reverse and small direct currents through the rectifier. An expression for the current in the case of large hole concentrations is also given.

537.311.33:621.314.63 769
Theory of Rectification at a Metal/Semiconductor Contact—W. Schultz. (*Z. Phys.*, vol. 138, pp. 598–612; September 18, 1954.) A study is made particularly of the influence of the inversion layer. The analysis is presented for an excess semiconductor, but corresponding arguments hold for a defect semiconductor. On making simplifying assumptions which are generally valid for semiconductors with high mobility and long diffusion path, the rectification process can be described using diode theory for the electron current and Shockley's theory of *p-n* junctions for the hole current. An expression is derived for the blocking-layer capacitance as a function of bias voltage and of a parameter *V* which varies slightly with the bias. The temperature dependence of *V* is discussed.

537.311.33:621.314.632 770
Theory of Contact Phenomena—G. M. Abak'yants. (*Zh. Eksp. Teor. Fiz.*, vol. 27, pp. 333–346; September, 1954.) This theory of metal-semiconductor contacts takes into account the change of the mean kinetic energy ("heating") of electrons in an electric field. The contact resistance, at constant current, is calculated for both Schottky- and Davydov-type layers. In a discussion of a note by Burgess (2697 of 1953) it is pointed out that the Einstein equation does not apply and the diffusion coefficient *D* is approximately proportional to the product of the mobility and the mean energy of the electrons in the electric field. The expression for drift velocity should take into account the difference between the temperature of the electrons and the lattice, which gives rise to thermal currents, and also the effect of a nonuniform electric field in the contact region. Krömer's paper (2821 of 1953) is also briefly commented on.

537.311.33:621.314.632 771
Flow of Electrons and Holes through the Surface-Barrier Region in Point-Contact Rectification—M. Cutler. (*Phys. Rev.*, vol. 96, pp. 255–259; October 15, 1954.) Equations are derived for emission-controlled flow, taking account of nonequilibrium concentration of carriers on the semiconductor side of the barrier. A solution based on the assumption that part of the voltage drop occurs between the metal and semiconductor surfaces, rather than entirely in the barrier, leads to improved agreement between theoretical and observed current/voltage characteristics. The part played by diffusion is also discussed.

537.311.33:621.396.822 772
Some Notes on Gisolf's Theory of Electron Fluctuation Phenomena in Semiconductors—K. W. Böer. [*Ann. Phys.* (*Lpz.*), vol. 15, pp. 55—56; September 15, 1954.] Correction to paper abstracted in 2139 of 1954.

537.529:621.315.61 773
The Statistical Time Lag of the Dielectric

Breakdown of Mica, Glass and KCl—H. Kawamura, H. Ohkura and T. Kikuchi. [*Jour. Phys. Soc.* (*Japan*), vol. 9, pp. 541–545; July/August, 1954.] Results of pulse measurements indicate that the statistical time lag at 10 per cent overvoltage is up to 10^{-4} second for mica but $\not>10^{-7}$ second for glass and KCl. Theories of the breakdown mechanism are discussed in the light of these figures.

538.221 774

Ferromagnetism of Certain Manganese-Rich Alloys—E. R. Morgan. [*Jour. Metals* (*New York*), vol. 6, pp. 983–988; September, 1954.] Report of an investigation of a series of alloys based on the composition $(MnX)_4C$, where X is a metallic element which has both a positive size factor with respect to Mn and a high positive valence, e.g. Al, In and Sn. Measurements indicate that the effective magnetic moment of Mn in the alloys is at least 1.0 Bohr magneton per atom.

538.221 775

Study of Strip Ferronickels around the Curie Point, using Weak Alternating Fields—A. Marais. [*Compt. Rend. Acad Sci.* (*Paris*), vol. 239, pp. 873–875; October 11, 1954.] Curves are given showing the variation of initial permeability with temperature for some Ni-Fe-Cu alloys containing either Mo or Cr in addition. The influence of specimen thickness and duration of heat treatment is indicated.

538.221:537.533.8 776

Nickel Alloys with High Secondary Emissivity—A. Bobenrieth, J. Millet and S. Teszner. [*Compt. Rend. Acad. Sci.* (*Paris*), vol. 239, pp. 794–796; October 4, 1954.] Ni-Be alloys with Be content up to 5 per cent by weight were prepared in a hf oven at low pressure. Measurements of the secondary emissivity are reported on specimens with 4 per cent and with 3 per cent Be, using primary electron voltages between 300 and 800 v and collector voltages between 100 and 500 v. Values up to 96 were recorded for the 4 per cent alloy and up to 45 for the 3 per cent alloy. With secondary electron currents $\not>1$ ma, no signs of fatigue were observed in the 4 per cent alloy over test periods of 8 hours. Ni-Mg alloys were prepared containing up to 1.2 per cent Mg. The highest value of secondary emissivity obtained was 2.

538.221:538.632 777

Hall Effect in Ferromagnetics—C. Kooi. (*Phys. Rev.* vol. 95, pp. 843–844; August 1, 1954.) Measurements on Si-Fe alloys are reported briefly; the results are in good agreement with values predicted theoretically by Karplus and Luttinger (698 above).

538.221:621.318.134 778

Some Properties of Nickel-Zinc Ferrites—L. I. Rabkin and B. Sh. Epshtein. (*Zh. Tekh. Fiz.*, vol. 24, pp. 1568–1578; September, 1954.) Experimental investigation is reported of the dependence of the magnetic properties of ferrites with mean permeabilities ranging from 40 to 2,500 on the frequency of the magnetic field (up to >10 mc), temperature between about -80 degrees C. and the Curie points (lying between 250 degrees C. and 80 degrees C.), and field strength up to ~ 1 oersted. The permeability and losses in weak pulsed fields and the dielectric properties were also investigated. Results are presented graphically; the code numbers denote the mean permeability in gauss/oersted.

538.221:621.318.134 779

Temperature Dependence of the Magnetic Properties of Nickel-Zinc and Copper-Zinc Ferrites—A. I. Suchkov. (*Zh. Tekh. Fiz.*, vol. 24, pp. 1579–1583; September, 1954.) Magnetic properties investigated experimentally include the saturation magnetization, saturation magnetostriction, coercive force, and initial and maximum permeabilities. Curie points of CuO-ZnO-Fe_2O_3 ferrites, of the molar compositions stated, lie between 30 degrees and 180 degrees C. Results are presented graphically and indicate that the general theory and the quantum theory of ferromagnetism also cover the temperature dependence of the magnetic properties of ferrites.

538.221:621.318.134 780

Neutron Diffraction Studies of a Nickel Zinc Ferrite—V. C. Wilson and J. S. Kasper. (*Phys. Rev.*, vol. 95, pp. 1408–1411; September 15, 1954.)

538.221:621.318.134.029.64/.65 781

On the Internal Field of the Microwave Resonance in Ferrites—N. Tsuya. (*Jour. Phys. Soc.* (*Japan*), vol. 9, pp. 644–645; July/August, 1954.] A possible mechanism is proposed which may cause the additional internal field.

538.221:669.14.018.58 782

Nature of Change of Coercive Force due to Tempering of Hardened Low-Carbon Steel—I. A. Bil'dzyukevich, Ya. M. Golovchiner and G. V. Kurdyumov. [*Compt. Rend. Acad. Sci.* (*URSS*), vol. 98, pp. 385–387; September 21, 1954. In Russian.] The effect of tempering of 0.1–0.12 per cent C steel, hardened by quenching in water from 1,100 degrees C. was investigated experimentally. Results indicate that the decrease of coercivity with increase of temperature (up to 600 degrees C.) is primarily due to the removal of strains in the steel.

538.652 783

Derivation of Magnetostriction and Anisotropic Energies for Hexagonal, Tetragonal, and Orthorhombic Crystals—W. P. Mason. (*Phys. Rev.*, vol. 96, pp. 302–310; October 15, 1954.) "In order to determine the measurements necessary to characterize the anisotropic energy and the saturation magnetostriction in hexagonal cobalt, a phenomenological derivation has been given for the equations which characterize the effects. Out to fourth rank tensors, the results are the same as those for circular symmetry and it requires two constants to specify the anisotropic energy and four to specify the magnetostriction. When sixth rank tensors are evaluated, a characteristic hexagonal symmetry appears. It requires four constants to characterize the anisotropic energy and nine to characterize the magnetostriction. These constants can be measured by using two oriented slabs. Four of the constants can be determined by measurements parallel to the saturation magnetization, four when the magnetostriction is perpendicular to the magnetization and one when they are 45 degrees apart. In the appendix the first approximations for the magnetostrictive and anisotropy energies are derived for tetragonal and orthorhombic crystals."

538.652 784

Magnetostriction and Crystal Anisotropy of Single Crystals of Hexagonal Cobalt—R. M. Bozorth. (*Phys. Rev.*, vol. 96, pp. 311–316; October 15, 1954.) Measurements at field strengths up to 25,000 oersted are reported. Results are discussed in terms of theory developed by Mason (783 above). A volume contraction associated with domain orientation was observed, its value being as great as 26×10^{-6} for the most effective direction of magnetization. Superposed on this contraction is an isotropic increase of volume of 0.6×10^{-9} per oersted.

538.652:538.221 785

The Magnetostriction Constants of Silicon Steel: Part 1.—H. Takaki and Y. Nakamura. (*Jour. Phys. Soc. Japan*, vol. 9, pp. 507–511; July/August, 1954.) Magnetization measurements using a ballistic method and magnetostriction measurements using a mechano-optical method were made on long single-crystal specimens of 0.7 per cent and 1.8 per cent Si steel; the magnetostriction constants λ_{100} and λ_{111} and the crystal-anisotropy constant K_1 were hence determined. The results confirm that these three constants decrease as the Si content increases.

538.652:538.221 786

Temperature Dependence of Magnetostriction of Ferromagnetic Alloys—D. I. Volkov and V. I. Chechernikov. (*Zh. Eksp. Teor. Fiz.*, vol. 27, pp. 208–214; August, 1954.) The saturation-magnetostriction/temperature characteristics of Ni-Cu, Ni-Mn, and Ni-Fe alloys were determined by means of a tensometer method at temperatures up to the Curie point. Results, which are presented graphically, are in good agreement with theory.

539.23:537.311.3 787

Resistance of Thin Metal Films at High Frequency and Low Temperature—S. Offret and B. Vodar. [*Compt. Rend. Acad. Sci.* (*Paris*), vol. 239, pp. 1027–1029; October 27, 1954.] Results of measurements indicate that short-circuiting by intergranular capacitances is probably responsible for the decrease of resistance at high frequency and for the increase in the algebraic value of the temperature coefficient of resistance. At sufficiently high frequencies it should be possible to measure the resistance of the metal grains themselves.

621.315.613.1 788

Synthetic Mica Investigations: Part 5—A Low-Shrinkage Machinable Ceramic of Phosphate-Bonded Synthetic Mica—J. E. Comeforo. (*Jour. Amer. Ceram. Soc.*, vol. 37, pp. 427–432; September 1, 1954.) Total shrinkage is easily maintained at <3 per cent with a material formed by pressing powdered synthetic mica with phosphoric acid as binding agent. The dielectric properties approximate to those reported [784 of 1954 (Comeforo et al.)] for hot-pressed phosphate-free material of similar porosity. Loss factor is 1–2 per cent at room temperature and 4–8 per cent at 300 degrees C. at a frequency of 1 mc. The material is suggested as a substitute for natural block talc.

621.315.616:537.533.9 789

Irradiated Polyethylene—J. B. Campbell. (*Mater. and Meth.*, vol. 40, pp. 91–95; September, 1954.) The effect on polyethylene of bombardment by high-voltage electrons is described; details are given of commercially available material in tape form. Unlike ordinary polyethylene, the irradiated material is not thermoplastic; its use may permit reduction in size of electrical equipment operating at high temperatures. Dielectric strength at high temperature may be improved by the treatment.

621.372.412:549.514.51 790

Effect of Acoustic Impedance and Viscosity of Gases on the Electrical Constants of Quartz—S. Parthasarathy and V. Narasimhan. [*Ann. Phys.* (*Lpz.*), vol. 15, pp. 6–14; September 15, 1954. In English.] Experimental results show that the equivalent electrical resistance of a quartz crystal is proportional to the acoustic impedance of the gas in which it is vibrating; the Q factor decreases exponentially with increasing viscosity, as in liquids, but the relation is approximately linear over the small range involved. The natural frequency of the crystal used was 414,216 kc.

621.39:621.791.3 791

Investigations on Soldered Joints—H. Künzler and H. Bohren. (*Tech. Mitt. schweiz. Telegr.-Teleph. Verw.*, vol. 32, pp. 329–351; September 1, 1954. In German.) Chemical and physico-chemical problems are discussed. Tests were made to find a solder with a noncorrosive flux. The influence of temperature on the structure of soldered materials and the quality of the joints was studied. The wear of Cu soldering irons is much reduced if the solder contains some Cu.

666:539.61:669 792
Frictional Adhesion of Metal to Glass, Quartz, and Ceramic Surfaces—R. B. Belser. (*Rev. Sci. Instr.*, vol. 25, pp. 862–864; September, 1954.) Experiments were made using small disks of various metals rotated at high speed in contact with the various insulator surfaces; by suitably adjusting speeds and pressures a layer of metal was made to adhere securely. The process may be useful for making glass-to-metal joints and electrically conducting lines, and for glass cutting.

MATHEMATICS

512.393 793
Solution of Cubics and Quartics—G. Millington: A. C. Sim. (*Wireless Eng.*, vol. 32, p. 30; January, 1955.) Comment on 187 of January and author's reply. An error in the original paper is corrected.

519.281 794
Method of Averages and its Comparison with the Method of Least Squares—M. Morduchow. (*Jour. Appl. Phys.*, vol. 25, pp. 1260–1263; October, 1954.) Comparison of the two methods is illustrated by treating the problem of fitting a straight line to a number of points. It is shown that the standard deviation of the residuals by the method of averages is at most $2/\sqrt{3}$ times as great as that by the method of least squares.

517.9 795
Relaxation Methods [Book Review]—D. N. de G. Allen. Publishers: McGraw-Hill Book Co., New York and London, 1954, 257 pp., $7.50. (*Science*, vol. 120, pp. 423–424; September 10, 1954.) A strongly recommended textbook, giving descriptions of the basic operations and their application.

MEASUREMENTS AND TEST GEAR

53.088 796
Sensitivity—a Criterion for the Comparison of Methods of Test—J. Mandel and R. D. Stiehler. (*Jour. Res. Nat. Bur. Stand.*, vol. 53, pp. 155–159; September, 1954.) "If M is a measure of some property Q, and σ_M its standard deviation, the sensitivity of M, denoted ψ_M is defined by the relation $\psi_M=(\mathrm{d}M/\mathrm{d}Q)/\sigma_M$. It follows from this definition that the sensitivity of a test method may or may not be constant for all values of the property Q. A statistical test of significance is derived for the ratio of sensitivities of alternative methods of test. Unlike the standard deviation and the coefficient of variation, sensitivity is a measure of merit that is invariant with respect to any functional transformation of the measurement, and is therefore independent of the scale in which the measurement is expressed."

621.316.842(083.74) 797
Recent Development of Standard Resistors—A. Schulze. (*Elektrotech. Z.*, *Edn A*, vol. 75, pp. 547–550; September 1, 1954.) The construction and manufacture of sealed-in standard resistors is described. The temperature coefficient of resistance has been reduced to 1×10^{-6} in 97.95 Au/2.05 Cr alloy resistors by heat pre-treatment, and to 10×10^{-6} in manganin-wire resistors. The change of resistance of the Au/Cr standards is of the order of 1×10^{-6} over a period of 3 to 5 years.

621.317.3.029.63:534.62 798
Construction of a Reflection-Free Room for Sound Waves and Decimetre Electrical Waves—Epprecht, Kurtze and Lauber. (*See* 612.)

621.317.33 799
A Two-E.M.F. Method for the Comparison of Resistances—H. J. Hoge. (*Rev. Sci. Instr.*, vol. 25, pp. 902–907; September, 1954.) Two sources of emf, each with an associated dropping resistor, are respectively connected in series with two resistors to be compared in such a way that the latter are not adjacent; the circuit is adjusted so that the potentials at the corresponding ends of the two resistors are equal when they carry equal currents. The method permits continuous observation or recording without error due to uncontrolled change of resistance in the connections.

621.317.333.6:621.372.8 800
Electrical Breakdown in Waveguides at 3000 Mc/s—Sutherland. (*See* 640.)

621.317.335 801
Measurement of Permittivity and Tangent of Loss Angle of Dielectrics with High Absorption at Centimetre Wavelengths—E. Briganti. (*Poste e Telecomun.*, vol. 22, pp. 327–332; July, 1954.) A cavity-resonator method suitable for liquid specimens is described. Rigorous but simple formulas are derived for determining the permittivity and loss angle from measurements of wavelength and power.

621.317.337:621.372.413 802
Nomogram for Q of a Cavity—J. D. Harmer. (*Wireless Eng.*, vol. 32, pp. 25–27; January, 1955). A nomogram is presented with the aid of which the Q factor can be determined from a small number of measurements of the standing waves in a feeder coupled to the cavity.

621.317.41/.42:621.395.625.3 803
Experimental Determination of [magnetic] Parameters of Magnetic-Recording Media—G. S. Veksler and P. S. Tomashevski. (*Zh. Tekh. Fiz.*, vol. 24, pp. 1594–1598; September, 1954.) Description, with circuit diagram, of cro apparatus for tracing $4\pi I/H$ curves at frequencies up to $>10^4$ cps. Photographs of typical hysteresis loops are presented including one showing also the initial part of the curve.

621.317.7:621.396.822:621.385 804
A Multichannel Noise Spectrum Analyzer for 10–1000 c/s—E. G. Nielsen and A. van der Ziel. (*Rev. Sci. Instr.*, vol. 25, pp. 899–902; September, 1954.) An instrument for rapid analysis of flicker noise in tubes is described. Values of either the equivalent saturated diode current or the equivalent noise resistance at 10, 30, 100, 300, 1,000, 3,000 and 10,000 cps are obtained simultaneously by feeding the signal into seven parallel channels each incorporating a wide-band RC filter and a thermistor square-law detector.

621.317.715:621.375.13.029.424 805
A Tuned Galvanometer Amplifier—J. R. Beattie and G. K. T. Conn. (*Rev. Sci. Instr.*, vol. 25, pp. 888–891; September, 1954.) Description of a system consisting of a galvanometer tunable by feedback over the range 1–3 cps, followed by an electronic amplifier covering the same frequency range (2950 of 1953), for amplifying signals from a radiation thermocouple used with a low-frequency interrupter. The output is presented as a rectified smoothed meter deflection. The amplification is sufficient to reveal thermal noise in the thermocouple circuit.

621.317.73 806
A Goniometer Quotient-Measurement Method for the Direct Determination of Admittance—H. Fricke. (*Funk u. Ton.* vol. 8, pp. 225–238 and 369–377; May and July, 1954.) Voltages proportional respectively to the current through the unknown impedance and the voltage across it are applied to the crossed coils of a goniometer, phase equalization being effected by a tuned circuit or a short-circuited transmission line across the unknown impedance. Calibration curves for 1-mc operation are given; error can be kept within a given limit, say 1 per cent, over different ranges by adjustment of series resistance and goniometer coupling; sensitivity is improved by a two-goniometer system. Circuits and goniometer arrangement for operation at uhf are described. A possible application of the equipment with a cro for displaying locus curves is outlined.

621.317.733 807
Modern Bridge Techniques—P. M. Ratcliffe. (*Marconi Instr.*, vol. 4, pp. 167–175; September, 1954.) A concise review.

621.317.733:621.316.86:537.312.6 808
A Self-Balancing Thermistor Bridge—A. F. Standing. (*Jour. Sci. Instr.*, vol. 31, pp. 343–344; September, 1954.) A direct reading of power in the range 0.1–10 mw is obtained by including the thermistor in an oscillatory feedback circuit such that the thermistor resistance is held constant. The oscillator output is balanced against a direct voltage to give a zero meter reading in the absence of rf power.

621.317.74:621.315.212 809
R.F. Cable Characteristics measured with a Q-Meter—J. Shekel. (*Electronic Eng.*, vol. 26, pp. 540–542; December, 1954.) Theory and practical details are given for a method in which a Q-meter determination of the frequency at which a section of the cable becomes a $\lambda/2$ resonator enables the propagation velocity, the characteristic impedance and the attenuation of the cable to be computed. A numerical example is included.

621.317.74+621.317.772:621.397.5:535.623 810
Differential Phase and Gain Measurements in Color-Television Systems—Kelly. (*See* 871.)

621.317.742:621.3.018.756 811
Direct V.S.W.R. Readings in Pulsed R.F. Systems—L. A. Rosenthal and G. M. Badoyannis. (*Electronics*, vol. 27, pp. 162–165; December, 1954.) Development of the ratio meter previously described [466 of 1953 (Rosenthal et al.)] to deal with pulse systems such as radar. Thermionic diodes are used as detectors. Pulse stretching is found necessary; a suitable circuit is shown. Operating procedure is outlined and measurements with standard and other loads are reported.

621.317.742:621.315.212 812
A Coaxial Standing-Wave Indicator for Frequencies near 10,000 Mc/s—F. A. Benson and G. V. G. Lusher. (*Electronic Eng.*, vol. 26, pp. 534–537; December, 1954.) Details are given of the construction of a precision instrument.

621.317.75:631.396.3 813
Response of Radio Spectrometers to Non-periodic Morse Signals—J. Marique. (*Ann. Télécommun.*, vol. 9, pp. 215–223 and 247–255; July–September, 1954.) The analysis is presented for the same arrangement of cascaded tuned circuits as discussed in previous studies (e.g. 2034 of 1954); expressions are derived for the currents in these circuits. The envelope-response of the circuit is defined and the conditions are investigated for this response to be sufficiently independent of the circuit design for practical purposes.

621.317.755 814
Measurement of an Impedance by means of a Double-Trace Cathode-Ray Oscillograph: Coincidence Method—A. Grumbach. [*Compt. Rend. Acad. Sci.* (*Paris*), vol. 239, pp. 869–871; October 11, 1954.] The unknown impedance is connected in series with a known impedance across the output terminals of a sine-wave generator, one of these terminals being earthed while the other is connected to one of the cro deflection systems. The second deflection system is connected to the junction between the impedances. The known impedance is varied to produce phase coincidence between the two curves; amplitude coincidence is produced by means of amplifiers. The sensitivity of the method is discussed in relation to meas-

urement of the permittivity and conductivity of a capacitor dielectric. Use of the arrangement for measuring frequency is also indicated. The frequency range is up to 100 kc.

621.317.755 815

Wide-Band Amplitude Distribution Analysis of Voltage Sources—L. W. Orr. (*Rev. Sci. Instr.*, vol. 25, pp. 894–898; September, 1954.) Signals to be analyzed are applied to a cro fitted with a slotted mask through which the luminescence output is fed to a photocell, the required amplitude distribution function being displayed on a second cro. The apparatus can be set up and operated quickly, and the accuracy is within 5 per cent. Analyses of two noise sources are shown.

621.317.755:621.385.3/.5 816

Development of a Characteristic-Curve Tracer for Transmitting Valves—J. Kammerloher and H. Krebs. (*Funk u. Ton*, vol. 8, pp. 453–470; September, 1954.) Description of a dc-pulse cro suitable for dealing with positive grid voltages. Circuit diagrams and some details of the switching arrangements are included. Typical curves obtained are reproduced; these include I_a/V_a curves for I_a up to $2A$, V_a up to 1,000 v and grid voltages of 0, 60, ... 300 v. An ac-pulse instrument is briefly mentioned.

621.317.761:621.374.3 817

A Pulse-Interval Meter for measuring Pulse Repetition Frequency—A. M. Andrew and T. D. M. Roberts. (*Electronic Eng.*, vol. 26, pp. 469–474 and 543–547; November and December, 1954.) The instrument described is suitable for use in cases such as neurophysiological measurements where the pulse repetition frequency varies rapidly. The output voltage at any instant is determined either by the duration of the preceding pulse interval, or by the duration already attained by the current interval, whichever is the longer. Frequency is indicated on an approximately linear scale, either by oscilloscope or by moving-coil meter.

621 396.001.4 818

Prediction of Electronic Failures—(*Elect. Jour.*, vol. 153, pp. 717–718; September 3, 1954.) The N.B.S. experimental failure-prediction unit is based primarily on the detection of a decrease in tube transconductance in successive stages of the equipment under test, which requires slight modification to enable stages to be tested separately. Provision for checking capacitors for leakage, and for voltage and current measurements is also made.

OTHER APPLICATIONS OF RADIO AND ELECTRONICS

534.1–8:669 819

Metallurgical Effects of Ultrasonic Waves—E. A. Hiedemann. (*Jour. Acous. Soc. Amer.*, vol. 26, pp. 831–842; September, 1954.) A survey with 121 references.

534.88 820

Echo-Location for the Blind—C. M. Witcher and L. Washington, Jr. (*Electronics*, vol. 27, pp. 136–137; December, 1954.) Developments are described in devices of the type emitting high-frequency clicks which are reflected by obstacles. The sound projector is rotated through an angle of 60 degrees in a period of 0.7–1 second by means of a miniature motor. A model for attachment to clothing weighs $1\frac{3}{4}$ pound.

621.314.214.5:621.317.39 821

Differential Transformers for Mechanical Measurements—L. W. Blick. (*Jour. Brit. IRE*, vol. 14, pp. 603–610; December, 1954. Discussion, p. 611.) Circuits for use with this type of transformer are described and applications as transducers are indicated.

621.316.7 822

A Design Philosophy for Man-Machine Control Systems—H. P. Birmingham and F. V. Taylor. (Proc. I.R.E., vol. 42, pp. 1748–1758; December, 1954.) Methods are described for designing control systems so that the human operator is required to act only as a simple amplifier. Aided tracking is discussed in relation to efforts to improve the stability of man-machine systems by the use of special equalization networks.

621.316.718:534.85:621.94 823

Magnetic Tape controls Machine Tools—J. W. Hogan. (*Electronics*, vol. 27, pp. 144–147; December, 1954.)

621.317.39 824

Three Electronic Thickness Gages for Metallic Coatings—(*Tech. News Bull. Nat. Bur. Stand.*, vol. 38, pp. 127–132; September, 1954.) Three instruments are described, in all of which operation depends on the difference in electrical conductivity between the plating and the support metal. The "dermitron" and the phase-angle thickness meter are electromagnetically coupled to the specimen and make use of the reflected field from eddy currents induced in the specimen. The "wageguide plating quantity indicator" makes a direct measurement of conductivity, using point electrodes.

621.317.39 825

Wire Strain-Gauge Transducers for the Measurement of Pressure, Force, Displacement, and Acceleration—J. L. Thompson. (*Jour. Brit. IRE*, vol. 14, pp. 583–600; December, 1954. Discussion, pp. 600–601.) Construction, theory of operation, and applications are discussed.

621.317.39 826

Load-Cell Force Transducers—D. L. Johnston. (*Jour. Brit. IRE*, vol. 14, pp. 613–620; December, 1954. Discussion, p. 620.) A chart is presented indicating ranges of power level and conversion efficiency for various types of transducer; the strain-gauge load-cell type is particularly useful for dealing with large forces. Associated measuring circuits are discussed.

621.317.79:621.385:531.717.3 827

Electronic-Mechanical Transducers—L. A. Goncharski. (*Zh. Tekh. Fiz.*, vol. 24, pp. 1711–1723; September, 1954.) Theory and practical considerations are discussed of a sensitive electron-tube-type transducer consisting basically of a thin, electrically heated filament between a pair of plate electrodes, one of which is operated as anode. The two plates are rigidly attached by through leads to a glass pinch, flexibly sealed in the container wall, which picks up the displacements to be measured. Using a constant anode current of 1.5 ma, with >90 v on the anode and -10 v on the other plate, the voltage sensitivity is $\sim$6,000 v per cm displacement of the plates. The current sensitivity is of the order of 0.1 a/cm-displacement. References to previous papers on the applications of this transducer are given.

621.365.55:674 828

Electronic Heating and the Woodworking Industry—M. T. Elvy. (*Jour. Brit. IRE*, vol. 14, pp. 547–566; November, 1954. Discussion, p. 567.) A review of hf dielectric heating methods with particular reference to the use of synthetic resin glues. The design of oscillation generators and coupling systems, jigs and electrodes is discussed.

621.384.612 829

Suppression of Coherent Radiation by Electrons in a Synchrotron—J. S. Nodvick and D. S. Saxon. (*Phys. Rev.*, vol. 96, pp. 180–184; October 1, 1954.)

621.384.612 830

Phase Oscillations in the Strong-Focusing Synchrotron—E. Bodenstedt. [*Ann. Phys.* (*Lpz.*), vol. 15, pp. 35–54; September 15, 1954.] Phenomena connected with the acceleration of particles beyond the critical-energy region in the strong-focusing synchrotron [1454 of 1953 (Courant et al.)] were investigated using a mechanical analog machine. Acceleration of particles beyond the critical energy can be accomplished by means of an odd number of jumps of the oscillator phase or by modulation of the oscillator voltage.

621.384.612 831

Project for an Electron Synchrotron in Italy—G. Salvini. (*Nuovo Cim.*, Supplement to vol. 12, pp. 77–100; 1954.) Plans are discussed in some detail for a 600-mev machine to be available for all nuclear physics work in Italy; the desirability of raising the energy to 1,000 mev is indicated.

621.384.612 832

Amplitudes of Oscillations in the Strong-Focusing Synchrotron—J. Seiden. [*Compt. Rend. Acad. Sci.* (*Paris*), vol. 239, pp. 798–800; October 4, 1954.] Simple formulas are presented.

621.384.612 833

Effects on Orbits of Correlation between Lens Alignment Faults in the Synchrotron—J. Seiden. [*Compt. Rend. Acad. Sci.* (*Paris*), vol. 239, pp. 966–968; October 18, 1954.)

621.384.622.1:537.533.9 834

Applications of High-Energy Electrons to the Sterilization of Pharmaceuticals and the Irradiation of Plastics—C. W. Miller. (*Jour. Brit. IRE*, vol. 14, pp. 637–652; December, 1954. Discussion, p. 652.) For irradiating the materials discussed, the available energy can be used more efficiently by electron bombardment than by X- or γ-rays. The required high-energy electrons should be obtained from a linear accelerator rather than a radioactive source. Practical and economic aspects of the use of linear accelerators are discussed. Over 50 references.

621.384.622.2 835

A Theory of Electron-Beam Loading in Linear Accelerators—G. Saxon. (*Proc. Phys. Soc.*, vol. 67, pp. 705–716; September 1, 1954.) Analysis is presented for the waveguide circuit of a linear accelerator using rf power feedback, to determine how the power flowing into such an accelerator varies with the beam loading. The relations derived are used in conjunction with formulas for the energy gain and beam power output of a length of accelerator waveguide to calculate the performance to be expected under feedback conditions as the beam current is varied. The calculated results are in reasonable agreement with measurements.

621.385.833 836

The Application and Limitations of the Edge-Diffraction Test for Astigmatism in the Electron Microscope—M. E. Haine and T. Mulvey. (*Jour. Sci. Instr.*, vol. 31, pp. 326–332; September, 1954.)

621.385.833 837

Rigorous Calculation for a Typical Electrostatic Unipotential Lens—W. Glaser and P. Schiske. [*Optik* (*Stuttgart*), vol. 11, nos. 9 and 10, pp. 422–443 and 445–467; 1954.]

621.385.833 838

Centering of Magnetic Electron Lenses—S. Leisegang. [*Optik* (*Stuttgart*), vol. 11, no. 9, pp. 397–406; 1954.)

621.387.4 839

The Reliability of Nucleonic Instruments—D. Taylor. (*Jour. Brit. IRE*, vol. 14, no. 11, pp. 570–580; November, 1954. Discussion, p. 580.) The servicing of nucleonic instruments under factory conditions is discussed; problems encountered in the British Atomic Energy Project are considered. Annual failure rates of some of the standard instruments are given; these are highest for the more orthodox com-

ponents, such as tubes and resistors. U. S. and Canadian figures are also quoted. Design principles are derived from the analyses presented.

621.387.424 840
Secondary Electron Emission by Photo-electric Action and Ion Bombardment at the Cathode in Corona Breakdown of Argon—L. Colli and U. Facchini. (*Phys. Rev.*, vol. 96, pp. 1–4; October 1, 1954.) Discussion of secondary-emission mechanisms in cylindrical argon-filled counter tubes with positive axial wire.

621.398.029.62:525.6 841
Radio-Linked Unattended Tide Gauge for Persian Gulf—[*Engineer* (*London*), vol. 198, p. 305; August 27, 1954.] A 27-w vhf transmitter is keyed by a series of half-second pulses generated by a balance wheel system; the number of pulses is controlled by a plunger system operated by a tide drum and gives a coded indication of tide height over a range −1 to +13 feet. The transmitter is supplied by NiFe cells charged automatically. The output of a receiver 12 miles away is fed to an integrator which operates an indicator scaled in divisions of 0.1 foot.

PROPAGATION OF WAVES

538.566:551.510.535 842
Focusing Phenomena due to Undulations of the Ionosphere, and Determination of Collision Number—K. Rawer and É. Argence. [*Compt. Rend. Acad. Sci.* (*Paris*), vol. 239, pp. 1066–1067; October 27, 1954.] An approximate formula is given for the amplitude of echoes for a reflecting surface with sinusoidal undulations. The effect of the curvature becomes preponderant near the focus state $r=ph_0$, where r is the radius of curvature, p the order of the echo, and h_0 the height of the ionized layer. The parameters involved can be calculated from the amplitudes of three successive echoes, most conveniently observed at night. The curvature effect is useful for re-interpreting old observations giving reflection coefficients greater than unity. Adopting the hypothesis that collisions are mostly between electrons and neutral molecules, a collision number of about 400 is found for the middle of the F_2 layer during winter nights.

621.396.11+621.396.9+523.16 843
Propagation of Electromagnetic Waves, Radio Location and Radio Astronomy—E. Roessler. (*Elektrotech. Z., Edn A*, vol. 75, pp. 632–635; September 11, 1954.) A brief survey of recent progress, particularly since 1951. 73 references.

621.396.11:551.510.5 844
Central Radio Propagation Laboratory of the N.B.S.—[*Engineer* (*London*), vol. 198, pp. 401–404; September 17, 1954.] See 3018 of 1954.

621.396.11.029.62:551.51 845
A Study of Some of the Meterological Effects on Radio Propagation at 96.3 Mc/s between Richmond, Va. and Washington, D. C.—D. L. Randall. (*Bull. Amer. Met. Soc.*, vol. 35, pp. 56–59; February, 1954.) "For meteorological observations during which the wind speeds were equal to or greater than 10 m.p.h., and when fronts, low overcast clouds (less than 5,000 feet), rain, thunderstorms and fogs were excluded, a 0.70 correlation coefficient was found between hourly surface refractive index and hourly median field strength."

621.396.81 846
Theoretical Field Strengths and Angles of Incidence of WWV Transmissions at the Châtonnaye Receiving Station—C. Glinz. (*Tech. Mitt. schweiz. Telegr.-Teleph. Verw.*, vol. 32, pp. 253–267; July 1, 1954. In German.) German version of paper abstracted in 3668 of 1954.

621.396.81 847
Some Observations on Rayleigh Fading—B. van der Pol. (*Tijdschr. ned. Radiogenoot.*, vol. 19, pp. 223–229; September, 1954. In English.) Fading due to multipath propagation is discussed on the basis of the random-walk problem. A formula is presented from which (a) the most probable, (b) the median, and (c) the mean signal amplitude is evaluated. The method of obtaining the Rayleigh distribution curve from a typical fading record is shown. The distinction between Rayleigh fading and fading due to variation of ionospheric absorption is emphasized.

621.396.812.3.029.53:551.510.535 848
Periodic Fading of Medium-Wave Radio Signals—Rao and Sarma. (*See* 714).

RECEPTION

621.376.232.2.015.7 849
Pulse Response of Signal Rectifiers—M. V. Callendar. (*Wireless Eng.*, vol. 32, pp. 3–14; January, 1955.) An examination is made of the loading imposed by a diode rectifier on a tuned circuit from which it is fed. The response time for the circuit together with the diode is investigated, both directly and via the modulation-frequency response characteristic. Measurements are reported confirming the theory for the simplest case of a single circuit centrally tuned and yielding information on the response with more complex wideband amplifiers. Comparison is made with the performance of a triode detector. The most important practical conclusion is that no advantage is gained by using a shunt resistor across the circuit to provide damping.

621.396.62(43) 850
New German Broadcast Receivers—O. Limann. (*Elektrotech. Z., Edn. B*, vol. 6, pp. 347–351; September 21, 1954.) Improved sensitivity, selectivity and fidelity are features of the 1954 models. The triode Type-ECC85 is used almost universally as low-noise USW first-stage tube; the medium-slope Type-EF89 pentode has advantages for the IF stage. Distortion in the af stages has been reduced by two-channel amplification and other methods; side loudspeakers are used in some models.

621.396.621+621.37]:621.314.7 851
Some Transistor Circuits—van Overbeek. (*See* 650.)

621.396.621.54 852
A.M./F.M. Communications Receiver—(*Wireless World*, vol. 61, pp. 41–43; January, 1955.) Description and performance report of a commercial model with continuous tuning over the range 19-165 mc in six bands. The IF is 5.2 mc. Rf, oscillator and mixer stages form a single unit; the six-position rotary-coil turret, three-gang split-stator capacitors and other components are arranged so as to minimize the amount of wiring.

621.396.821:519.2 853
Study of Statistical Models suggested by Consideration of the Effects of Atmospherics on Amplifiers—A. Blanc-Lapierre, M. Savelli and A.Tortrat. (*Ann Télécommun.*, vol. 9, pp. 237–245; September, 1954.) An analysis is made of the output of a linear amplifier to whose input is applied (a) Gaussian noise with uniform spectrum, and (b) random pulses with a Poisson distribution in time. Consideration is given to the limiting condition when the density of the Poisson distribution is very high. A method of calculating the instantaneous amplitude distribution is developed. The case of a train of very short pulses is dealt with, and properties of the detected voltage are discussed.

621.396.621 854
Radio Receiver Design—Part I [Book Review]—K. R. Sturley. Publishers: Chapman & Hall, London, Eng., 2nd ed., 667 pp., 58s. (*Jour. Sci. Instr.*, vol. 31, p. 347; September, 1954.) Revised and augmented to a length about 50 per cent greater than that of the first edition. "The book should be a useful and reliable guide to those concerned with circuits for radio frequencies or with the characteristics of radio receivers."

STATIONS AND COMMUNICATION SYSTEMS

621.376.56 855
Experimental Model for Pulse-Number Modulation—J. Holzer, G. Missriegler, E. Niedermayr, H. Putschi and H. Zemanek. (*Öst. Z. Telegr. Teleph. Funk Fernsehtech.*, vol. 8, pp. 125–132; September/October, 1954.) Description of equipment installed at the Technische Hochschule at Vienna. The principle of operation is to convert the lf signal into width-modulated pulses which are in turn converted into groups containing corresponding numbers of narrow equal-width pulses; these are counted in a binary system and the results give the code group. 32-step quantization is used. Decoding is performed by causing the received pulses to charge a capacitor which is discharged through a resistor, the time constant of the system being made equal to t_0/log 2, where t_0 is the time spacing of the pulses in the code group.

621.376.56 856
Reception of Code-Modulation Signals by Integration—H. Harmuth. (*Fernmeldetech. Z.*, vol. 7, pp. 461–464; September, 1954.) See 2505 of 1954.

621.39:621.372.8 857
Waveguide as a Communication Medium—Miller. (*See* 641.)

621.39.001.11 858
1954 Symposium on Information Theory—(*Trans. I.R.E.*, no. PGIT-4, pp. 1–227; September, 1954.) The text is given of the following papers presented at the symposium held at the Massachusetts Institute of Technology in September, 1954:

"A New Basic Theorem of Information Theory,"—A. Feinstein (pp. 2–22).
"Binary Coding,"—M. J. E. Golay (pp. 23–28).
"Error-Free Coding,"—P. Elias (pp. 29–37).
"A Class of Multiple-Error-Correcting Codes and the Decoding Scheme,"—I. S. Reed (pp. 38–49).
"Coding for Constant-Data-Rate Systems,"—R. A. Silverman and M. Balser (pp. 50–63).
"Information, Organization and Systems,"—J. Rothstein (pp. 64–66).
"An Information-Theoretical Model of Organizations,"—M. Kochen (pp. 67–75).
"Simulation of Self-Organizing Systems by Digital Computer,"—B. G. Farley and W. A. Clark (pp. 76–84).
"A Study of Ergodicity and Redundancy based on Intersymbol Correlation of Finite Range,"—S. Watanabe (pp. 85–92).
"Multivariate Information Transmission,"—W. J. McGill (pp. 93–111).
"Choice and Coding in Information Retrieval Systems,"—C. N. Mooers (pp. 112–118).
"Modern Statistical Approaches to Reception in Communication Theory,"—D. Van Meter and D. Middleton (pp. 119–145).
"A Nonlinear Prediction Theory,"—R. F. Drenick (pp. 146–162).
"The Detection of Signals perturbed by Scatter and Noise,"—R. Price (pp. 163–170).
"The Theory of Signal Detectability,"—W. W. Peterson, T. G. Birdsall and W. C. Fox (pp. 171–212).
"The Human Use of Information: Part 1—Signal Detection for the Case of the Signal Known Exactly,"—W. P. Tanner, Jr., and J. A. Swets (pp. 213–221).
"The Human Use of Information: Part 2—

. Signal Detection for the Case of an Unknown Signal Parameter,"—W. P. Tanner, Jr., and R. Z. Norman (pp. 222–227).

621.39.001.11 859

Note on a Theorem of Shannon—S. De Francesco. (*Ann. Geofis.*, vol. 7, pp. 195–207; April, 1954.) The formula given in Shannon's "sampling theorem" (1649 of 1949) is shown to correspond to complete convergence of a generalized Fourier-series expansion. An expression is derived for the inherent error.

621.395.44:621.375.2 860

Line Amplifiers for Symmetrical Carrier Frequency Cables—F. Feil. (*Fernmeldetech. Z.*, vol. 7, pp. 454–460; September, 1954.) Amplifier types V12, V60 and V120 for the German Post Office system are described. As a result of advances in design, the V120 is smaller and consumes less power than the V12. A comparison table of the most important data is presented.

621.396.3 861

Predicted-Wave Radio Teleprinter—M. L. Doelz. (*Electronics*, vol. 27, pp. 166–169; December, 1954.) The "predicted-wave" system is a particular form of frequency-shift. The detection circuits accumulate over each pulse period the signal and noise from each of the two frequency channels in high-Q magnetostrictive resonators; a mark or a space is registered according as the accumulated amplitude is greater in the mark channel or in the space channel. A synchronizing signal is transmitted on a frequency of 23.04 kc, midway between mark and space frequencies. Performance figures are given; an error rate of 0.1 per cent was obtained with signals 6 db below noise level in the IF band; this constitutes a considerable improvement over the performance of a conventional frequency-shift system.

621.396.3:621.317.75 862

Response of Radio Spectrometers to Nonperiodic Morse Signals—Marique. (*See* 813.)

621.396.712+621.397.743 863

Plans for F.M.-Radio and Television Networks in Denmark—G. Pedersen. [*Teleteknik* (*Copenhagen*), vol. 5, pp. 220–230; July, 1954.]

621.396.932 864

Radio Communication in the Merchant Marine—W. E. Steidle. (*Elektrotech. Z., Edn A*, vol. 75, pp. 584–587; September 11, 1954.) A brief account is given of the use made of the several frequency bands allocated to shipping, and of modern radio equipment used at sea.

621.39.001.11 865

Information Theory [Book Review]—S. Goldman. Publishers: Syracuse University, Prentice-Hall Inc., New York, N.Y., 1953, 385 pp., $9.00. (*Electronics*, vol. 27, pp. 360–362; December, 1954.) Intended for graduate students in electrical engineering. The treatment is based on Shannon's work; liberal use is made of examples.

SUBSIDIARY APPARATUS

621.314.63:546.28 866

Silicon Power Rectifier handles 1200 Watts—E. F. Losco. (*Electronics*, vol. 27, pp. 157–159; December, 1954.) A *p-n* fused-junction Si-Al rectifier with a junction area of 0.05 cm^2 is mounted in a copper radiator with a slotted periphery. High power-handling capacity is obtained by use of forced-air cooling. Characteristic curves are shown.

621.316.722 867

Direct-Voltage Stabilizers in the Range 10–100 kV with Particular Reference to Degenerative Systems—M. W. Jervis. (*Jour. Brit. IRE*, vol. 14, pp. 629–636; December, 1954.) The maximum usable loop gain depends on the frequency response of the system; in practice, loop gains of the order of 1,000 are possible, i.e. the effects of mains-voltage and load-current fluctuations are reduced by this factor. Reference elements are reviewed; wire-wound resistance potential dividers are the most stable, but electron-energy analysers give comparable stability with smaller size and current drain.

621.316.722.1 868

A 2 kVA A.C. Voltage Stabilizer—R. G. Ackland. (*Aust. Jour. Instr. Tech.*, vol. 10, pp. 98–101; August, 1954.) A motor-operated variac type of stabilizer is described, in which the voltage-sensing unit contains only one tube, of cold-cathode type, and incorporates biasing to hold the output voltage near the center of the control range. The output is maintained at 230 v$\pm$1 per cent (or $\pm$1 v if required). The correction rate is 10 v/second.

TELEVISION AND PHOTOTELEGRAPHY

621.397.5 869

Television Engineering [in Western Germany]—F. Kirschstein. (*Elektrotech. Z., Edn A*, vol. 75, pp. 638–640; September 11, 1954.) Brief survey of studio and industrial techniques, transmitters, receivers and microwave and cable links. 55 references.

621.397.5:061.3 870

Technical Conference of West German Broadcasting Authorities held at Munich, 24th–28th May 1954—(*Tech. Hausmitt. NordwDtsch. Rdfunks*, vol. 6, pp. 149–176; 1954.) Summaries are given of 29 papers dealing with various aspects of television. Subjects include transmission, studio equipment and techniques, television links, and measuring equipment.

621.397.5:535.623:[621.317.74+621.317.772 871

Differential Phase and Gain Measurements in Color-Television Systems—H. P. Kelly. [*Elec. Eng.* (*New York*), vol. 73, pp. 799–802; September, 1954.] Portable appartus suitable for color-carrier-frequency measurements in N.T.S.C. systems is described with the aid of block diagrams. Simplified circuit diagrams are also given of sections of the test transmitter and receiver.

621.397.5:535.767 872

Stereo-Television—H. Dewhurst. (*Jour. Telev. Soc.*, vol. 7, pp. 279–285; July/September, 1954.) A review of possible methods. Only those involving viewer aids appears to be practicable. 33 references.

621.397.61 873

An Experimental Camera Circuit for 405 Lines—C. H. Banthorpe. (*Jour. Telev. Soc.*, vol. 7, pp. 300–303; July/September, 1954). A simple camera for scanning still pictures and captions makes use of a Type-5527 iconoscope, with es focusing and deflection. Brief descriptions are given of the vision pre-amplifier, black-level clamp, spurious-signal remover, picture and synchronizing-signal mixer, blanking-pulse amplifier, scanning circuits and power supply.

621.397.62 874

Frame Flyback Suppression—W. T. Cocking. (*Wireless World*, vol. 61, pp. 33–35; January, 1955.) An explanation is given of the fact that the flyback trace is commonly visible at the receiver notwithstanding that the form of the television signal is designed to render this part of the trace invisible. Circuits for deriving a suppression pulse from the frame timebase are described, this pulse can be applied, with appropriate polarity, to either grid or cathode of the picture tube.

621.397.62:621.397.335 875

A Critical Review of Synchronizing Separators with Particular Reference to Correct Interlacing—G. N. Patchett. (*Jour. Brit. IRE*, vol. 14, p. 621; December, 1954.) Discussion on 2527 of 1954.

621.397.621.2:621.385.832 876

Transfer Characteristics and Mu Factor of Picture Tubes—H. Moss: K. Schlesinger. (PROC. I.R.E., vol. 42, p. 1809; December, 1954.) Comment on 2171 of 1953 and author's reply.

621.397.7 877

The Television Centre at Hamburg-Lokstedt—E. Schwartz. (*Fernmeldetech. Z.*, vol. 7, pp. 468–472; September, 1954.) A brief description. For a detailed account see *Tech. Hausmitt. NordwDtsch. Rdfunks*, vol. 5, nos. 7/8; 1953.

621.396.712+621.397.74.3 878

Plans for F.M.-Radio and Television Networks in Denmark—G. Pedersen. [*Teleteknik* (*Copenhagen*), vol. 5, pp. 220–230; July, 1954.]

TRANSMISSION

621.396.61:621.396.3 879

Keying V.L.F. Transmitters at High Speed—M. I. Jacob and H. N. Brauch. (*Electronics*, vol. 27, pp. 148–151; December, 1954.) Naval communication technique is discussed; transmitters with power ranging from 250 kw to 1 mw and operating at frequencies from 15 to 35 kc are used. High-speed frequency-shift keying is made possible by varying the resonance frequency of the antenna in synchronization with the signal-frequency variation. This is done by connecting a saturable reactor across the antenna. Successful teleprinter transmissions have been made over distances >5,000 miles, using an output of 450 kw.

TUBES AND THERMIONICS

621.314.632:546.289 880

Transient Phenomena in the Backward Direction of Germanium Crystal Rectifiers—M. Kikuchi and Y. Tarui. (*Jour. Phys. Soc. Japan*, vol. 9, pp. 642–644; July/August, 1954.) Theory based on the heating process involved is developed to account for the step variation of the current observed in point-contact rectifiers on sudden application of reverse voltage. The step occurs at the instant when the contact temperature reaches a critical value, estimated to be about 80 degrees C. This result is supported by observations.

621.314.632:546.289:537.312.6 881

An Additional Observation on Thermal Effects in Point Contact Rectifiers—H. L. Armstrong (*Jour. Appl. Phys.*, vol. 25, p. 1345; October, 1954.) Addendum to 1242 of 1954.

621.314.7 882

The Effect of a Transverse Electric Field on Carrier Diffusion in the Base Region of a Transistor—J. S. S. Kerr, J. S. Schaffner and J. J. Suran. (*Jour. Appl. Phys.*, vol. 25, pp. 1293–1297; October, 1954.) Analysis is presented for a junction transistor with parallel emitter and collector junctions and a field applied across the base in a direction parallel to the junctions. An expression is obtained for the current gain as the sum of terms each having the same form as that found by Steele (881 of 1953) for the one-dimensional case.

621.314.7 883

Expression for the "α Cut-Off" Frequency in Junction Transistors—D. Haneman. (PROC. I.R.E., vol. 42, pp. 1808–1809; December, 1954.) The expression $\omega_c = \kappa D_M/W^2$, where D_M is the diffusion constant for minority carriers in the base region of width W, has been used by a number of workers, and various values have been proposed for κ. A method of solution is indicated for nonzero values of W/L_m, where L_m is the diffusion length; in this case κ is a

slowly varying function of W/L_M, with a value around 2.5. Results obtained are in qualitative agreement with observations, in particular the prediction that ω_c is more sensitive to variations of collector voltage if ω_c is initially high.

621.314.7:621.318.57 884
Large-Signal Behavior of Junction Transistors—J. J. Ebers and J. L. Moll. (PROC. I.R.E., vol. 42, pp. 1761–1772; December, 1954.) Analysis relevant to the use of transistors for switching is based on recognition of three distinct dc operating conditions defined by Anderson (652 of 1953) and corresponding to the on, off, and transition states. Expressions for the impedance in the open and in the closed state are derived in terms of easily measurable transistor parameters. The influence on switching time of the alpha cut-off collector capacitance and minority carrier storage is considered.

621.314.7:621.318.57 885
Large-Signal Transient Response of Junction Transistors—J. L. Moll. (PROC. I.R.E., vol. 42, pp. 1773–1784; December, 1954.) Analysis is based on the three distinct operation states defined previously (884 above). A calculation is made of carrier storage time, or time required for the operating point to move from the collector-current-saturation state to the intermediate state. The alpha cut-off frequency ω_N is the most important parameter affecting switching speed. It is possible with moderate driving current to switch the operating point from collector-current-cut-off to collector-current-saturation in a period of the order of $3/\omega_N$ sec; to permit switching at this speed in the opposite direction, carrier storage effects must be avoided.

621.314.7.002.2 886
Manufacturing Grown Junction Transistors—F. H. Bower. (*Electronics*, vol. 27, pp. 130–134; December, 1954.) A step-by-step account of the procedure.

621.385.029.6 887
Some Recent Advances in Microwave Tubes—J. R. Pierce. (PROC. I.R.E., vol. 42, pp. 1735–1747; December, 1954.) A review covering high-power klystrons, double-tuned circuits for reflex klystrons, reduction of noise in traveling-wave tubes by velocity-jump or space-charge-wave de-amplification, periodic magnetic focusing of the beam, and the backward-wave oscillator. 23 references.

621.385.029.6 888
The Wave Picture of Microwave Tubes—J. R. Pierce. (*Bell. Sys. Tech. Jour.*, vol. 33, pp. 1343–1372; November, 1954.) The low-level operation of long-beam tubes such as klystrons, resistive-wall amplifiers, easitrons, space-charge-wave amplifiers, traveling-wave tubes and double-stream amplifiers is discussed in terms of the waves propagated.

621.385.029.6 889
Equations for the Oscillations in Uniform Electron Beams—Yu. A. Katsman. (*Zh. Tekh. Fiz.*, vol. 24, pp. 1359–1360; July, 1954.) Addendum to 3144 of 1953.

621.385.029.63/.64 890
Focusing of a Long Cylindrical Electron Stream by means of Periodic Electrostatic Fields—Ping King Tien. (*Jour. Appl. Phys.*, vol. 25, pp. 1281–1288; October, 1954.) Space-periodic fields produced by a bifilar helix or a series of annular rings are considered. The potential distribution is given in the form of a power series and the equation of electron motion is derived. The solution indicates that the flow is essentially parallel provided the electrons have low transverse velocity on entering the focusing structure and are distributed transversely so that the transverse distribution of space-charge field is similar to that of the focusing field. Numerical examples relevant to the design of traveling-wave tubes are presented. The use of a bifilar helix to provide both retardation and focusing is discussed.

621.385.029.63 891
Scalloped Beam Amplification—T. G. Mihran. (*Jour. Appl. Phys.*, vol. 25, p. 1341; October, 1954.) Brief account of experiments on a tube in which electron bunching is produced by the usual control grid close to the cathode, to which a 1-kmc signal is applied, and alternate debunching and bunching occur along the beam under the influence of a longitudinal magnetic field only. Rf power gain and beam diameter are plotted against beam drift distance. An over-all gain of 24 db was measured, of which 10.6 db resulted from the "scalloped-beam" amplification.

621.385.032.216:621.396.822 892
On the Flicker Noise Generated in an Interface Layer—H. J. Hannam and A. van der Ziel. (*Jour. Appl. Phys.*, vol. 25, pp. 1336–1340; October, 1954.) The equivalent noise resistance R_n of a tube due to the oxide-cathode interface layer is proportional to the square of the interface resistance R_i and inversely proportional to f^α, where f is the frequency and α ranges from 1.1 for low values of R_i to 1.5 for high values of R_i, at af. Experiments are reported proving that the noise originates in the interface layer. Measurements at hf indicate an increase in the value of α.

621.385.2:621.376.232.2.029.63/.64 893
Mechanism of Rectification in Vacuum-Tube Diodes at Microwave Frequencies—G. Papp. (*Elec. Commun.*, vol. 31, pp. 215–219; September, 1954.) The equations of motion of the electrons are derived. Calculation of the diode current indicates that appreciable rectification is obtained; this is confirmed by measurements. Similar work has been reported by Bronwell et al. (3096 of 1954).

621.385.2.032.216 894
Effects of Cathode and Anode Resistance on the Retarding-Potential Characteristics of Diodes—G. C. Dalman. (*Jour. Appl. Phys.*, vol. 25, pp. 1263–1267; October, 1954.) Anomalous retarding-potential characteristics of diodes with oxide cathodes are explained by taking account of high-resistance layers at cathode and anode; an improvement is thereby obtained in the accuracy of estimating the cathode temperature.

621.385.3 895
Amplification Factor and Perveance of an Elliptic Triode—S. Deb and G. S. Sanyal. (*Jour. Appl. Phys.*, vol. 25, pp. 1196–1203; September, 1954.) Expressions for the amplification factor μ, interelectrode capacitance, and perveance P of the triode are derived using a conformal transformation to reduce the elliptic geometry to plane geometry. Results indicate that μ depends on the parametric angle θ of the ellipse and that the average value of μ increases as the grid eccentricity increases and as the anode eccentricity decreases. Curves are presented for finding μ when the value of θ is known. The value of P depends mainly on the grid eccentricity and the focal distance. The theory is illustrated by considering the design of a Type 6C5-GT/G tube.

621.385.3/.5:621.317.755 896
Development of a Characteristic-Curve Tracer for Transmitting Valves—Kammerloher and Krebs. (*See* 816.)

621.385.3.029.63 897
The Design of Triodes for U.H.F. Medium-Level Power Amplifiers—W. E. Rowlands. *Electronic Eng.*, vol. 26, pp. 522–527; December, 1954.) Tubes with parallel-plane electrode systems are considered, for operation at about 2 kmc with output of about 10 w. An expression si derived for radiant-heat dissipation in the grid, and an estimate is made of the influence of the heat-reflection coefficients of the electrodes. Particular attention is devoted to problems arising from cathode evaporation in conjunction with the close spacing of electrodes. A relation between evaporation rate and increase of grid-wire diameter is derived, and the effect of grid growth on tube operating parameters and on tube life is investigated. A life of about 10,000 h appears possible.

621.385.5:621.396.822 898
Partition Components of Flicker Noise—T. B. Tomlinson. (*Jour. Brit. IRE*, vol. 14, pp. 515–526; November, 1954.) In a pentode, the reduction of flicker noise obtained by operating under space-charge-limited conditions (281 of 1953) is to some extent canceled as a result of the partition of the current between anode and screen grid. Noise measurements made with the tube connected (a) normally and (b) as a triode confirm the existence of this partition component and provide information on the origin of the flicker noise. Defects giving rise to excessive noise at low frequencies were encountered in standard type tubes examined.

621.385.832 899
Dark-Trace Display Tube has High Writing Speed—S. Nozick. N. H. Burton and S. Newman. (*Electronics*, vol. 27, pp. 154–156; December, 1954.) A cathode-ray tube is described in which a high value of beam current for a given spot size, and hence high writing speed, is obtained by using an auxiliary focusing system to reduce the beam diameter in the region of the deflection coils. Writing speeds up to 15 km have been attained.

621.387 900
A Magnetic Gas-Discharge-Tube Oscillator—J. M. Somerville. (*Jour. Sci. Instr.*, vol. 31, pp. 279–284; August, 1954.) If a glow discharge is established between an axial cylindrical anode and an outer cylindrical cathode split transversely into two differently biased sections, then, in the presence of a magnetic field, the conductance between the two cathode sections will, under particular operating conditions, be negative. The effects of various factors on the conductance and the efficiency of the tube as an oscillator are discussed. The frequency range is up to about 50 kc, and efficiencies up to 70 per cent are attainable. A mercury-vapor split-cathode tube suitable for commercial production is also described.

621.314.7 901
Transistoren [Book Review]—M. J. O. Strutt. Publishers: S. Hirzel Verlag, Zurich and Stuttgart, 1954, 166 pp., DM21. (*Arch. elekt. Übertragung*, vol. 8, pp. 371–372; August, 1954.) "... the main emphasis of the book is on the technical application of transistors."

MISCELLANEOUS

061.4:621.3 902
Ninth Annual Electronics Exhibition, Manchester—(*Instrum. Practice*, vol. 8, pp. 703–711; August, 1954.) Illustrated account of the exhibition held in July, 1954.

621.38+621.39 903
Fortschritte der Hochfrequenztechnik, Band 3. [Book Review]—F. Vilbig and J. Zenneck (Eds.). Publishers: Akademische Verlagsgesellschaft Geest and Portig K.-G., Leipzig, 1954, 718 pp., DM49. (*Frequenz*, vol. 8, p. 198; June, 1954.) Progress reports include surveys on radio-propagation conditions in various wavebands, the sun and ionosphere, traveling-wave tubes, radio-interference suppression, receiver engineering, frequency modulation, etc. A 36-page index is included.

Gulton abstracts 4

MATERIALS RESEARCH • ELECTRONIC COMPONENTS • PRECISION INSTRUMENTS • SYSTEMS ENGINEERING

Variable reluctance pressure gauge has high accuracy over a wide frequency range

Glennite PVR-200-1 Pressure Gauge
Specifications: Frequency response, 0-500 c.p.s.; Natural frequency, 5 KC or higher; Linearity, better than ±1.5% full scale; Pressure ranges, ±100 mm Hg, ±5 psi, ±10 psi; Temperature range, —67° F to +120° F; Size, 11/16" D., 5/16" high; Weight, 12.5 grams.

The new Glennite PVR-200 series pressure gauges fulfill the requirements of industry for subminiature differential pressure transducers of high accuracy and performance over a wide frequency range.

These rugged gauges are designed to transform differential air or gas pressure into a measurable electrical signal which can be utilized by standard instruments.

Exceedingly versatile, they can measure static or slowly varying pressures, as well as those fluctuating at frequencies well into the audio range. These flexible, dynamic test instruments can be easily and accurately calibrated.

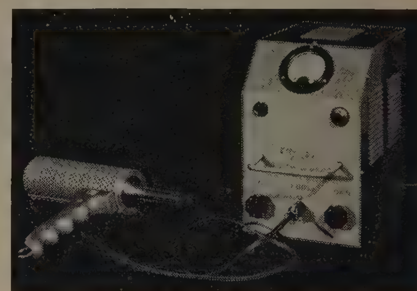
Because of their outstanding characteristics, the Glennite PVR-200 gauges permit research where pressure measurement was hitherto difficult or impractical, as in flight testing. In stationary installations, such as wind tunnels, they can be used in confined spaces to measure rapidly varying phenomena which are beyond the capabilities of manometers or the conventional bulky pressure pickup. The transducers are engineered to work with commercially available carrier amplifier systems.

Gulton Mfg. Corp.

New, portable ultrasonic soldering iron eliminates use of flux

The Glennite Ultrasonic Soldering Iron, Model U-611, is an electrically heated, ultrasonically driven tool for soldering such materials as aluminum and magnesium and their alloys without the use of corrosive flux. It is invaluable for soldering metals or alloys that form refractory oxides and eliminates special surface pre-treatment.

Lightweight, small size and portable, the unit can operate in areas not accessible to bench work. Uses include assembly and installation of wave guides, surface tinning and filling of voids in aluminum or magnesium castings.



Model U-611 Soldering Iron

Only 35 watts are needed to drive the soldering tip to sufficiently agitate the molten solder and remove oxide films.

The 9" x 9" x 6" generator, supplied with the soldering iron, has an input of 117 volts at 1 ampere, 60 cycles. It has gain control, off-on power switch and fine frequency tuning control. A gas heated ultrasonic soldering iron, Model U-610, is also available for soldering large components.

Vibro-Ceramics Corporation

Friction-free meter achieves high sensitivity, ruggedness and precision

The radically new Greibach Meter employs a unique bifilar suspension movement.

In the Greibach movement the rotating coil is centrally suspended by taut twin wires anchored to precisely tensioned spiral disc springs. Virtually friction-free construction eliminates bearings or pivots, and delicate hair or coil springs. A light beam pointer minimizes inertia effects and eliminates parallax errors, permitting reading from any angle; no tapping is necessary.

Standard meters utilizing the Greibach Bifilar Suspension are made with sensitivities up to 1 microampere full-scale. This performance is achieved with only 4500 ohms internal resistance, an accuracy of better than 0.25%, an ability to survive high mechanical shocks and momentary electrical overloads of up to 100,000%! Panel and laboratory meters are available for DC and AC voltage and current measurements and for precision resistance measurements.

Greibach Light Pointer Precision Meter

Greibach Instruments Corporation

Gulton Industries, Inc.

201 Durham Ave., Metuchen, New Jersey

- ☐ Put me on Gulton Abstracts mailing list

Please send me additional information on:

- ☐ Glennite Ultrasonic Soldering Irons
- ☐ Greibach Meters
- ☐ Glennite PVR-200 Variable Reluctance Gauges
- ☐ Glennite Electromechanical and Electronic Instruments
- ☐ Glennite Electronic Components

NAME

TITLE

COMPANY

ADDRESS

GULTON INDUSTRIES, INC. Gulton Mfg. Corp. • Glenco Corporation • Vibro-Ceramics Corporation • Greibach Instruments Corporation • Thermistor Corporation of America

Membership

(Continued from page 78A)

Zaphiropoulos, R., 7887 Sunkist Dr., Oakland, Calif.
Zill, F. W., 5000 Gulf Freeway, Houston, Tex.

The following elections to the Associate grade were approved to be effective as of March 1, 1955:

Adams, C. B., 5100 San Francisco Ave., St. Louis 15, Mo.
Adikaram, K. B., 416-A New Rd., Panadura, Ceylon
Anderson, O. A., 4435 General Dr., Beaumont, Tex.
Anderson, T. E., Parkway Apts., 66-D, Haddonfield, N. J.
Arnell, E. B., 107-06—122 St., Richmond Hill 19, L. I., N. Y.
Asch, B., 80 Lawrence Dr., N. White Plains, N. Y.
Atkins, J. W., Jr., Chance Vought Aircraft, Dept. 55180, Dallas, Tex.
Bachrach, H. E., Bermudez F-32, La Lucila, Buenos Aires, Argentina
Balacki, S. J., 49-09—103 St., Corona 68, L. I., N. Y.
Bauman, V. R., 12315 Washington Pl., Los Angeles 66, Calif.
Bederka, S. E., General Electric Co., French Rd., Utica 4, N. Y.
Bekker, D., 21 Shoshanim, Tiv'on, Haifa, Israel
Bender, W. W., 6106 Bertram Ave., Baltimore 14, Md.
Bennett, L., 765 Third Ave., New York 17, N. Y.
Bergh, F. H., 1307 Whitswing, McAllen, Tex.
Berquist, A. O., 602 Mission St., Apt. 2, San Antonio 3, Tex.
Bezaire, W. A., 4105 Wisconsin Ave., N.W., Washington 16, D. C.
Bingham, T. V., 2500 Willowbrook Dr., Cincinnati 15, Ohio
Birge, W. A., 4-C Alder Dr., Baltimore 20, Md.
Bloomquist, L. A., 8258 S. Halsted St., Chicago 20, Ill.
Blum, H. E., 2734—74 Ave., Hyattsville, Md.
Blymiller, A. L., Mounted Rt., Dale Rd., Rome, N. Y.
Blusiewicz, E., 2257 Deheze, Buenos Aires, Argentina
Bow, B. H., 53 Garrison Rd., Brookline 46, Mass.
Bradbury, L. D., 5437 Dorado Ave., Orlando, Fla.
Brant, E. D., 1426 Bristol Ave., Westchester, Ill.
Briscoe, H. R., 403 Signal View, Chattanooga, Tenn.
Brunton, R. H., III, 105 Birds Hill Ave., Needham 92, Mass.
Buckley, R. O., 822 Gist Ave., Silver Spring, Md.
Cagney, W. M., 3545—78 St., Jackson Heights, L. I., N. Y.
Calvin, C. C., Jr., 1408 Paxton, Arlington, Tex.
Capers, J. L., 5611 Rideway Dr., Houston, Tex.
Carlile, R. N., Rm. 2754, Bldg. 12, Hughes Aircraft Co., Culver City, Calif.
Carlson, W. A., 93 Churchill Ave., Arlington 74, Mass.
Cary, S. L., 9835—82 Ave., Edmonton, Alta., Canada
Casey, P. J., 1229 E. 57 St., Chicago 37, Ill.
Casselman, W. G. B., 112 College St., Toronto 5, Ont., Canada
Chestnut, E. H., 1020-A South AlA, Patrick AFB, Fla.
Ciceroni, S., Via D'Azeglio 3/B, Rome, Italy
Clapp, M. F., 5527 W. Jefferson Blvd., Los Angeles 16, Calif.
Class, J. S., 746 Skyline Dr., Lancaster, Pa.
Cohen, I., 8030 Thuron Ave., Philadelphia 19, Pa.
Coleman, G. E., 509 Rogers Ave., Brooklyn 25, N. Y.
Collins, J. L., 3398th Tech. Ing. Sqdn., Box 86, Keesler AFB, Miss.
Coniber, G. A., 327 W. Colvin St., Syracuse 5, N. Y.
Conti, T. L., 34 Hilltop Rd., W. Long Branch, N. J.

(Continued on page 84A)

G.E.'s IMPROVED 6CD6-GA SWEEP TUBE IS COMPACT, STURDY...HAS NEW, HIGH RATINGS!

1. New bulb is straight-side, smaller and sturdier.

2. Redesigned, more shock-resistant tube structure. Redesigned plate, with larger area.

3. Bottom mica, as well as top, now contacts the glass, for greater rigidity. Both micas are completely redesigned to minimize arc-overs.

4. Button-stem base gives shorter and better-separated leads; improves heat conduction.

No price increase! Now one economical tube will serve in both monochrome and color TV sets!

NEW high-rating tube performance, arc-overs cut 'way down . . . yet price stays the same as the prototype 6CD6-G! Plate positive-pulse voltage now is 7,000 volts, against 6,600 volts. Plate dissipation has been increased one-third—from 15 watts to 20 watts.

Every 6CD6-GA gets an arc-over test at absolute max ratings. This built-in, tested-in freedom from tube arcing, with high-capacity performance as shown by the new ratings, makes G.E.'s new sweep tube equally suitable for color TV along with black-and-white.

Consequently, you need specify and stock only one tube for monochrome and color. You save on inventory . . . and save substantially on tube cost, at the 6CD6-GA's low price. Also, TV quality benefits. Fewer arc-overs mean less horizontal picture streaking.

To high-rating tube performance, add important structural improvements. These make the new 6CD6-GA more shock-resistant—far longer-lived. The tube also takes up less chassis space than before. Side-by-side X-ray pictures above show details of Type 6CD6-GA's new design.

Ask for complete information! *Tube Department, General Electric Co., Schenectady 5, New York.*

Also available: NEW 25CD6-GB. Same improved design and performance as 6CD6-GA, but has heavy-duty 600-ma heater with "series-string" warm-up time.

Progress Is Our Most Important Product

GENERAL ELECTRIC

162-1A2

Membership

(*Continued from page 82A*)

Copestakes, J. E., 3230 Friendship St., Philadelphia, Pa.
Corbin, S. A., 289 Ashford St., Brooklyn 7, N. Y.
Cude, H. H., Box 298, Duncanville, Tex.
Cyl-Champlin, C., 308-S West St., Arlington, Tex.
Dale, W. L., General Electric Co., AGT Division Development, Cincinnati 15, Ohio
Daw, E. H., 1133 Knickerbocker Dr., Sunnyvale, Calif.
Dean, F. A., 12703 Hathaway Dr., Silver Spring, Md.
De Halmy, A., 674 Roslyn Ave., Westmount, Montreal, Que., Canada
De Mesme, T. A., Box 1187, Haselton Branch, Rome, N. Y.
Dennis, D. L., 2026 Boyer Ave., Seattle 2, Wash.
Dennis, P. A., 2810 Tennyson Pl., Hermosa Beach, Calif.
Doran, T. F., 514 Girard-Hubbard Rd., Youngstown 4, Ohio
Dowe, R. J., 1215 Prytania St., New Orleans 13, La.
DuBois, R. O., Jr., Electro Mechanical Research, Ridgefield, Conn.
Efstathiou, J., 589 Merritt Ave., Oakland 10, Calif.
Ellsworth, B. E., 302 S. Maple, North Platte, Nebr.
Elliott, J. R., 408 Thurman Ave., Columbus 6, Ohio
Erdman, A. L., 6920th Security Wg., APO 73, San Francisco, Calif.
Favors, E. L., 844 N. 67 E. Ave., Tulsa, Okla.
Fluhrer, A. C., 318 N. Berendo St., Los Angeles 4, Calif.
Flynn, J. G., III, 6214 DeLoache, Dallas, Tex.
Freeze, R. C., 8601 Dyer St., El Paso, Tex.
Frewaldt, E. W., Box 1740, Wichita 1, Kan.
Furlong, G. F., 56 Sterling Ave., S., Kitchener, Ont., Canada
Galli, E. J., 1616 Bogart Ave., New York 62, N. Y.
Garritson, F. K., 3357 W. 132 St., Hawthorne, Calif.
Geiger, R. H., 173 Pascack Ave., Emerson, N. J.
Giampiccolo, P. M., 1767—58 St., Brooklyn 4, N. Y.
Glixon, H. R., 51 Alpine La., Hicksville, L. I., N. Y.
Goldstein, S., 149 Brighton 11 St., Brooklyn 35, N. Y.
Goodman, H. A., 14 E. 96 St., Brooklyn, N. Y.
Grabowski, J. H., 7405 Tennyson Pl., Hermosa Beach, Calif.
Greenstein, J. L., 4248 Bernadine Pl., San Diego 15, Calif.
Grosser, A. J., Jr., Box 246, R.F.D. 1, Hanover, Md.
Gyllenkrok, T.-G., Bjornstorp, Sweden
Halldorsson, T. J., 6 Nonnustig, Hafnarfirdi, Iceland
Halloran, T. F., 3 Edgehill Rd., Winchester, Mass.
Hankin, R. B., 7029 N. Greenview, Chicago, Ill.
Harper, J. T., 6515 Rosemont Ave., Baltimore 6, Md.
Harrold, G. B., Box 441, Tombstone, Ariz.
Harvey, G. C., 1165 Monument, Pacific Palisades, Calif.
Hatcher, C. M., 4454 Osprey St., San Diego 7, Calif
Hauf, J. C., III, 1608 Glen Keith Blvd., Baltimore 4, Md.
Hayes, C. R., Box 885, Oxnard, Calif.
Hennessy, Box 94, Hq. Sqdn. Sec., 5001st Air Def. Group, APO 731, c/o Postmaster, Seattle, Wash.
Hernaiz, S. C., 165 Manhattan Ave., New York 25, N. Y.
Hiers, K. G., Box 327, R.F.D. 2, Cocoa, Fla.
Hornung, S. A., 260—11 Ave., New York 1, N. Y.
Hughes, R. M., 1332 W. 15 St., Owensboro, Ky.
Huller, M., 2470 Corrientes, Buenos Aires, Argentina
Hurst, E., 532 Circle Dr., Burlington, N. C.
Ireland, R. O., 3532 Holboro Dr., Los Angeles 27, Calif.

(*Continued on page 86A*)

Solve your problems quickly and economically with —

STANDARD SIZE
ANTENNA CORES

— by GENERAL CERAMICS

Standardized Parts...

Specifying General Ceramics standard antenna rods assures maximum economy, greater uniformity of quality and faster deliveries. These new components of Ferramic "Q" are available in five standard lengths in both rods and plates.

Ferramic "Q" offers...

Complete stability in respect to age, shock, vibration and temperature. Additional advantages are higher Q and lower losses at all frequencies up to 30 megacycles. Basic toroidal and typical antenna rod measurements are shown below. Call, write or wire for prices, today!

	F-125 DIA. ROD .250″ ±.015″*	F-214 DIA. ROD .330″ ±.020″*	F-429 WIDTH .725″ ±.025″ THICKNESS .125″ +.030″ −.000″
LENGTH	PART NO.	PART NO.	PART NO.
7.520 ± 7/32	1	6	11
6.250 ± 3/16	2	7	12
5.300 ± 5/32	3	8	13
4.625 ± 1/8	4	9	14
4.100 ± 1/8	5	10	15

*Camber .011 per inch

BASIC TOROIDAL MEASUREMENTS

Initial Permeability μ_0 (1Mc)	125
Figure of Merit Q (1Mc)	400
Loss Factor $\frac{1}{\mu_0 Q}$ (1Mc)	.000020
(5Mc)	.000050
(10Mc)	.000130
(20Mc)	.000500
μ_0 vs Frequency Characteristics	Good to over 30 Mc
Q vs Frequency Characteristics	Good to over 30 Mc
Curie Temperature (°C)	350
Temp. Coeff. of μ_0(1Mc) %/°C (25°C to 70°C)	+0.10 max.
Temp. Coeff. of Q (Same units as above)	−0.75
Saturation Flux Density Bs (gauss) at Hdc = 25 oersteds	3300
Max. Permeability μ max	400
Coercive Force H (oersteds)	2.10
Residual Magnetism Br	1800

TYPICAL ANTENNA ROD MEASUREMENTS

FREQUENCY	Q	C = mmf.
0.6	310	360
0.8	331	200
1.0	325	126
1.2	325	85
1.4	310	63

TEMPERATURE COEFFICIENTS

Antenna Rod No. F-214 (.330 x 7.520″). Standard Test Coil—Space wound solenoid 85 turns #26 AWG. Formex copper, occupying approx. 90% of length of rod and centered on rod. (Resonates at 1 Mc. with 126 mmf.)

$$TC = \frac{\% \Delta \mu_0}{\mu_0} (25^\circ \text{ to } 75^\circ C)$$

Temp. Coeff. of Rod. +1.0 to +2.0
Temp. Coeff. of Coil only ≈ 0

General CERAMICS CORPORATION
TELEPHONE: VALLEY 6-5100
GENERAL OFFICES and PLANT: KEASBEY, NEW JERSEY

MAKERS OF STEATITE, ALUMINA, ZIRCON, PORCELAIN, SOLDERSEAL TERMINALS, LIGHT DUTY REFRACTORIES, CHEMICAL STONEWARE, IMPERVIOUS GRAPHITE, FERRAMIC MAGNETIC CORES

Membership

(*Continued from page 84A*)

Irwin, R. R., 638 Abington Ave., Glenside, Pa.
Jeanne, C. E., 200 Wood Rd., Whitesboro, N. Y.
Jensen, M. W., 656 Rosemont St., La Jolla, Calif.
Johnson, R. M., 359 Woodland Rd., Madison, N. J.
Jurriaans, G. F., 4821 W. Van Buren, St., Chicago 24, Ill.
Kasprazycki, E. J., 2312 N. Hoyne Ave., Chicago 47, Ill.
Kattoua, I. E., 883 Delaware, Detroit 3, Mich.
Katz, J., 576 E. 91 St., Brooklyn 36, N. Y.
Keating, L. M., 59 Tiel Way, Houston, Tex.
Keely, J. F., 1555 Nostrand Ave., Brooklyn 26, N. Y.
Keener, M. A., 4860 Pescadero Ave., San Diego 7, Calif.
Keller, A. L., 5 Park Vale, Brookline 46, Mass.
Kennaugh, E. M., 67 W. Patterson, Columbus, Ohio
Keroes, H. I., 369 Shure La., Philadelphia 28, Pa.
King, E. F., 22861 Edgewood Dr., St. Clair Shores, Mich.
King, M. L., 320 Dorn Ave., Bound Brook, N. J.
Klein, M. L., 23002 Ostronic Dr., Woodland Hills, Calif.
Kloepping, J., IBM Corp., Poughkeepsie, N. Y.
Kunkel, W. E., 2217 West Rd., Little Rock, Ark.
Kronlage, R. B., Jr., 647 Coleraine Rd., Baltimore 29, Md.
Kydd, J. G., 338 Queen St., Ottawa, Ont., Canada
Lamm, L. M., NAESU, Naval Receiving Station, Washington 25, D. C.
La Presti, P., 220 Knickerbocker Ave., Brooklyn 37, N. Y.
Levy, G., 100 Ringdahl Ct., Rome, N. Y.
Lindsay, W. J., Electronic Defence Group, Engineering Research
Institute, University of Michigan, Ann Arbor, Mich.
Little, B. W., 11316 Venice Blvd., Mar Vista 66, Calif.
Love, K. A., 1111 N. 18 Ave., Melrose Park, Ill.
Loveland, H. D., 4026 Oberlin, Houston 5, Tex.
Lunn, W. B., 11157 Braddock Dr., Culver City, Calif.
Lupano, E. L., 2717 Throop Ave., New York, N. Y.
Lydick, J. D., 1220 N.W. 37, Oklahoma City 18, Okla.
McCabe, R. P., 1470 Edward L. Grant Hwy., New York 52, N. Y.
McCormack, E. J., Box 250, 3337th Tech. Tr. Sqdn., Scott AFB, Ill.
McDonald, A. E., 1319 W. Ninth St., N. Little Rock, Ark.
McIver, D. A., 6303 Benbury Rd., Baltimore 12, Md.
McNamara, J. E., U. S. Steel Corp., 525 William Penn Pl., Pittsburgh, Pa.
Macgill, L. T., Jr., 576 N. Chestnut St., Westfield, N. J.
Manigold, F. E., Drawer D, Bloomfield, N. Mex.
Marinakos, L. C., 8244 Evans Ave., Chicago 19, Ill.
Maxwell, J. W., 3237-B Inwood Rd., Dallas 19, Tex.
Maestrini, R., 2 Via Oneto, Novi Ligure, Alessandria, Italy
Merkel, K., 66-33 Myrtle Ave., Glendale 27, N. Y.
Metzner, J. J., 87-49—62 Rd., Rego Park, L. I., N. Y.
Miles, W. J., 836 Berwyn St., Indianapolis 3, Ind.
Miller, F. J., 312 N. 23 St., Harrisburg, Pa.
Moeller, L. H., 1051 N. Kenwood, Baltimore 5, Md.
Morgan, E. K., 561—41 St., Brooklyn 32, N. Y.
Morris, H., 3840 Harrison St., N W., Washington 15, D. C.
Morrow, A. J., 111 Spindle Rd., Hicksville, L. I., N. Y.
Murray, P. C., 44 Central Dr., Bronxville 8, N. Y.
Myers, R. H., 2003 Huntington Dr., Arlington, Tex.

(*Continued on page 88A*)

Membership

(Continued from page 86A)

Nelson, J. S., Jr., 1910 Hillcrest Rd., Los Angeles, Calif.
Nelson, O. A., Box 23, Albany 6, Calif.
Nelson, W. C., 610 Garrett, Pasadena, Calif.
Nidus, L. S., 1324 Rosedale Ave., New York 72, N. Y.
O'Brien, E. D., 1060 S. Broadway, Rm. 807, Los Angeles, Calif.
Oefinger, H. C., Safety Center, 653 Main St., Stamford, Conn.
Ohlmann, G. A., 1295 Morningside Dr., Sunnyvale, Calif.
Oliver, E. F., 14 Diana La., N., Fairborn, Ohio
Phillips, W. E., Jr., 1221 Virginia Ave., Lakewood, Ohio
Podell, R. L., 1417 Chandler Dr., Fair Lawn, N. J.
Porat, D. I., Weizmann Institute of Science, Rehovoth, Israel
Pounds, W. H., 7432 Olive Tree La., Highland, Calif.
Quirk, J. B., 2133 Sunset Dr., Owensboro, Ky.
Rastovich, M., 7506 S.E. Reedway, Portland 6, Ore.
Reading, A., 33 Pine St., Hamilton, Ont., Canada
Regniere, J. P., 1090 Pere Marquette, Quebec, Que., Canada
Reilly, R. A., 48 Grant Ave., Somerville, N. J.
Reimherr, R. N., 4450 Gondar Ave., Long Beach, Calif.
Rhodes, W. H., 6902 Marlborough Rd., Baltimore 12, Md.
Risley, M. I., 118 S. 19 St., Omaha 2, Nebr.
Robbins, L. W., 17 Selfridge Rd., Reading, Mass.
Robinson, D. E., 4030 Maypole, Chicago 24, Ill.
Rossi, S., 500 Madison St., Hoboken, N. J.
Rubin, S., 237 Harvard, Malden 48, Mass.
Sanders, H. E., Controls, Bldg. 30, General Electric Co., Cincinnati, Ohio
Sang, W. W., 1202 E. Pontiac St., Fort Wayne, Ind.
Sarrafian, G. P., 4580 Bordeaux, Dallas, Tex.
Schmidt, H. L., 409 Dupont St., Toronto 4, Ont., Canada
Schock, H. E., Jr., Rittenhouse Claridge, Philadelphia 3, Pa.
Schroer, C. F., 7814 Maplewood Industrial Ct., St. Louis 17, Mo.
Schwartz, H., Electronic Fabricators, Inc., 682 Broadway, New York 12, N. Y.
Scott, W. A., 157 Saratoga Ave., Yonkers, N. Y.
Shaw, J. R., 10343 S. Morgan St., Chicago 43, Ill.
Shipe, J. J., 7322 Reeds Rd., Overland Park, Kan.
Shoemaker, H. M., 1362 S. Flower St., Los Angeles 15, Calif.
Olsen, R. T., 941 Jefferson Ave., Brooklyn, N. Y.
Osick, W. R., 4141½ Monroe St., Los Angeles, Calif.
Park, K. R., 64 Avenue De Salaberry, Quebec, Que., Canada
Paul, R. A., 2445 Laurier Blvd., Sillery, Que., Canada
Pena, H., Casilla de Correo #4, Lomas de Zamora, Buenos Aires, Argentina
Peters, J. D., Jr., 11 Hillside Ave., Chelsea 50, Mass.
Peterson, T. W., 233 Gray Pl., Apt. 402, Scott AFB, Ill.
Pierson, G. R., 17256 Horace St., Granada Hills, Calif.
Pinkstaff, J. R., 408 Shannon St., Schenectady, N. Y.
Plank, P. E., Newton Rd., Baltimore 19, Md.
Seth, H. P., 3846 W. Grand Ave., Chicago 51, Ill.
Simon, H., 3033 Brighton 14 St., Brooklyn 35, N. Y.
Smikle, K. R., 150-32—115 Rd., Jamaica 36, L. I., N. Y.
Smith, L. C., 1057 Prospect Ave., Westbury, L. I., N. Y.
Smith, L. L., Jr., 543 W. Butterfield Rd., Elmhurst, Ill.
Sokoloff, B. A., 32 Rue D'Alleray, Paris, Seine, France

(Continued on page 90A)

"Vibration Isolation" has helped solve the increasing problem of mechanical vibrations in high fidelity reproduction of sound.

For years, sound engineers have been plagued by mechanical vibrations caused by movement of grips, dollies and other studio equipment. And the progressive development of the high fidelity microphone has increased the importance of eliminating the adverse effects of these disturbances.

Faced with this problem, design engineers of a leading manufacturer of microphones and related electronic equipment consulted with LORD engineers. LORD's 30 years of experience and knowledge in vibration control resulted in a bonded tube-form joint of live rubber which effectively isolated mechanical vibrations from the microphone head.

"Vibration Isolation" is the answer to only one of the many problems presented to and solved by LORD engineers. If you are interested in producing tape recorders, microphones and other types of reproduction equipment, LORD engineers are ready to consult with you. Let them help you produce equipment of the most exacting professional standards with LORD rubber bonded products.

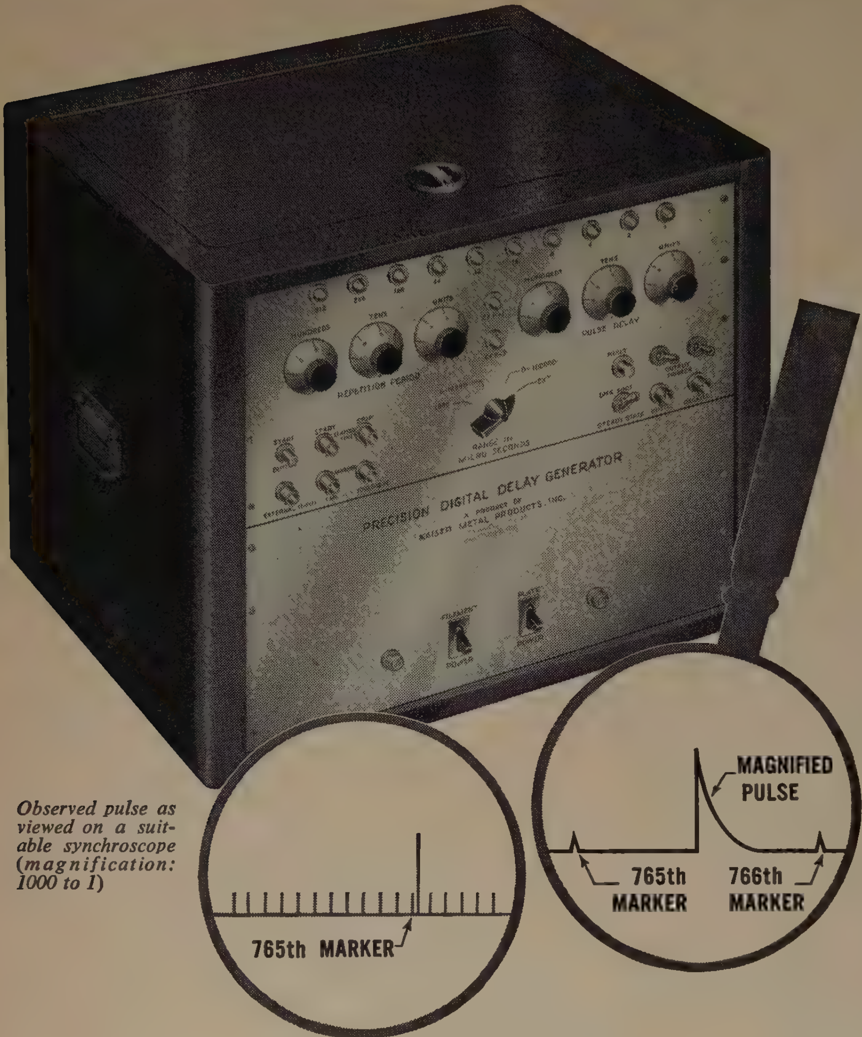
LOS ANGELES, CAL. HOllywood 4-7593	DALLAS, TEXAS RIverside 3392	DETROIT, MICH. TRinity 4-2060	NEW YORK, N. Y. Circle 7-3326
PHILADELPHIA, PENNA. LOcust 4-0147	DAYTON, OHIO MIchigan 8871	CHICAGO, ILL. MIchigan 2-6010	CLEVELAND, OHIO SUperior 1-3242

LORD MANUFACTURING COMPANY, ERIE, PA.

LORD BONDED RUBBER

DESIGNERS AND PRODUCERS OF BONDED RUBBER PRODUCTS SINCE 1924

ANNOUNCING!



Observed pulse as viewed on a suitable synchroscope (magnification: 1000 to 1)

A Precision Digital Delay Generator Providing Accuracies of Better Than .01 in 1000 Microseconds

Through unique application of digital circuitry and crystal controlled stability, this new development enables you to achieve accuracies never before approached in a unit of this type.

Continuous calibration is unnecessary with digital circuitry. Self-contained decimal to binary converters save many hours of costly laboratory set-up time. This advance in delay generators has many applications. It can be used for accurately measuring time delays; as a radar simulator; for supplying a single output pulse precisely delayed in time with respect to a reference pulse; as a secondary frequency standard, generating crystal controlled frequencies from 20 cycles to 1 megacycle in 3000 discrete steps; as an elapsed time indicator; and in many other similar functions.

Engineers working with radar, pulse circuitry, digital computer and navigational electronics find the Precision Digital Delay Generator an indispensable addition to the laboratory. Write for details.

FLEETWINGS DIVISION

KAISER METAL PRODUCTS, INC.

BRISTOL, PA.

IN THE HEART OF THE DELAWARE VALLEY

Membership

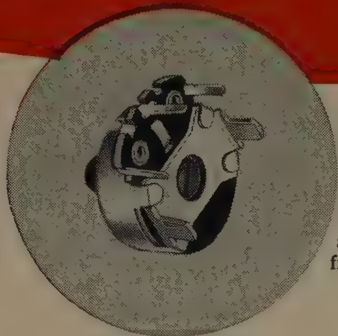
(Continued from page 88A)

Sperling, J., 55 Cooper St., New York 34, N. Y.
Steele, K. P., General Delivery, Fry, Ariz.
Stephens, J. F., 614 Glenn Ct., Owensboro, Ky.
Stevens, A. M., Jr., Vauxhall St., Ext., R.F.D. 2, New London, Conn.
Stevenson, D. D., 133 A Hornet, China Lake, Calif.
Stimpson, L. D., Jr., 3388 Rosewood Ave., Los Angeles 66, Calif.
Stripeika, A. J., 6204 Majestic Ave., Oakland 5, Calif.
Summers, C. R., 28110-B S. Abingdon, Arlington 6, Va.
Swing, R. E., 21 Notre Dame Rd., Bedford, Mass.
Sze, T. W., Electrical Engineering Department, University of Pittsburgh, Pittsburgh, Pa.
Tate, J. P., Jr., 2121 N. Hollister St., Arlington 5, Va.
Tetters, D. R., 3 B 212, Bell Telephone Laboratories, Whippany, N. J.
Thalmann, V., Gundeldingerstr. 325, Basel, Switzerland
Thomas, E. K., R.F.D. 2, 1 Peakham Cir., Sudbury, Mass.
Thomas, G. W., Box 133, R.F.D. 7, Oklahoma City, Okla.
Tibbits, A., c/o Young, Trott & Co., Ltd., Hamilton, Bermuda
Titherington, R. H., Jr., 15 Gibson St., Cambridge 38, Mass.
Todd, J., 924 Broadway, Boulder, Colo.
Toler, E. L., Jr., 522 Eighth St., Virginia Beach, Va.
Tringale, S. R., 141 Hillsdale Rd., W. Somerville, Mass.
Triplett, J. E., 6410 Knollbrook Dr., Hyattsville, Md.
Tyksinski, S. P., 3644 N. Leclaire Ave., Chicago 41, Ill.
Tylinski, F. V., Grayhill, 561 Hillgrove Ave., La Grange, Ill.
Verstrate, J. W., 22 A Vosmaerstraat, Rotterdam W., Holland
Vierling, H. D., 7915 Elmhurst Ave., Parkville 14, Md.
Visocnik, H. R., 1748 S. Fifth St., Columbus 7, Ohio
Vogel, R. P., 21 Young Ave., Yonkers, N. Y.
Wainscott, D. M., 110 W. Kirby Ave., Champaign, Ill.
Walker, D. H., 320 Willow Ave., Frederick, Md.
Walls, D. M., 3747 Eaton, Kansas City, Kan.
Warhurst, J. S., 194 Hubbard St., Glastonbury Conn.
Wessel-Berg, T., Stanford University, Microwave Laboratory, Stanford, Calif.
Whitley, W. M., 10949—109 St., Edmonton, Alta., Canada
Wiek, M. H., Jr., 99 Chapel Rd., Havre de Grace, Md.
Williams, H. C., Det. 4, 9470-TU, Ft. Hauchuca, Ariz.
Williamson, R. T., 216 Beach 126 St., Belle Harbor, N. Y.
Willner, W. H., Hazel Trail, Herald Harbor, Crownsville, Md.
Witlin, J. J., 1332 W. Sixth St., Brooklyn 4, N. Y.
Woods, E. L., 14035-C Dicky St., Whittier, Calif.
Worthington, R. L., 255 Prospect St., E. Orange, N. J.
Wott, H. W., 545 N. Locust St., Oak Harbor, Ohio
Young, E. A., c/o Hawk Eye Works, 20 Ave. E., Rochester 4, N. Y.
Ziegler, N. F., 121 W. Bryn Mawr Cr., Oak Ridge, Tenn.
Zimmerman, E. A., R.F.D. 1, New Ringgold, Pa.

Closing date for advertising 1955 IRE DIRECTORY June 15, 1955

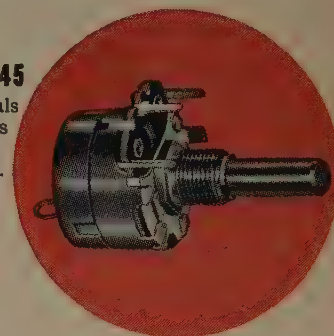
FOR YOUR AUTOMATION PROGRAM

RIABLE RESISTORS R PRINTED CIRCUITS

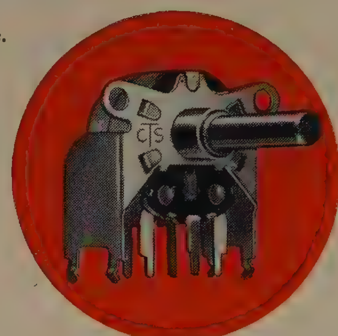


Type UPM-45
For TV preset control applications. Control mounts directly on printed circuit panel with no shaft extension through panel. Recessed screwdriver slot in front of control and 3/8″ knurled shaft extension out back of control for finger adjustment. Terminals extend perpendicularly 7/32″ from control's mounting surface.

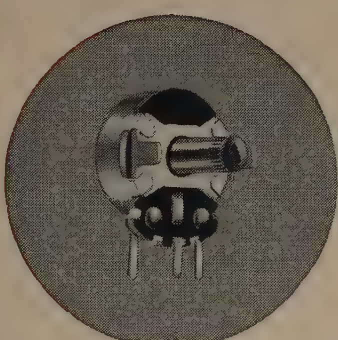
Type GC-U45
Threaded bushing mounting. Terminals extend perpendicularly 7/32″ from control's mounting surface. Available with or without associated switches.



Type U70 (Miniaturized)
Threaded bushing mounting. Terminals extend perpendicularly 5/32″ from control's mounting surface.



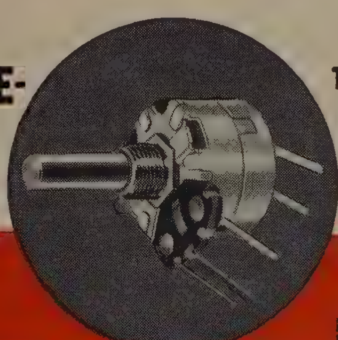
Type YGC-B45
Self-supporting snap-in bracket mounted control. Shaft center spaced 29/32″ above printed circuit panel. Terminals extend 1-1/32″ from control center.



Type XP-45
For TV preset control applications. Control mounts on chassis or supporting bracket by twisting two ears. Available in numerous shaft lengths and types.

Type XGC-45
For applications using a mounting chassis to support printed circuit panel. Threaded bushing mounting.

ARIABLE RESISTORS OR SOLDERLESS "WIRE-RAP" CONNECTIONS



Type WGC-45
Designed for solderless wire-wrapped connections with the use of present wire-wrapping tools. Available with or without switch and in single or dual construction.

The controls illustrated are typical constructions. CTS' years of engineering and technical experience makes available many other types for your automation needs.

CTS
CHICAGO TELEPHONE SUPPLY
Corporation
ELKHART • INDIANA
FOUNDED 1896

EAST COAST OFFICE
Henry E. Sanders
130 North Broadway
Camden 2, New Jersey
Phone: Woodlawn 6-1668
TWX No. Camden NJ 380
Phila. Phone: Market 7-3129

SOUTHWESTERN U.S.A.
John A. Green Company
6815 Oriole Drive
P.O. Box 7224
Dallas 9, Texas
Phone: Dixon 9918

SOUTH AMERICA
Jose Luis Pontet
Buenos Aires, Argentina
Montevideo, Uruguay
Rio de Janeiro, Brazil
Sao Paulo, Brazil

WEST COAST OFFICE
Robert A. Stackhouse
928 S. Robertson Blvd.,
Los Angeles 35, Calif.
Phone: Crestview 4-5931
TWX No. BEV H 7666

CANADIAN DIVISION
C. C. Meredith & Co., Ltd.
Streetsville, Ontario
Phone: 310

OTHER EXPORT
Sylvan Ginsbury
8 West 40th Street
New York 18, New York
Phone: Pennsylvania 6-8239

The Exclusive Specialists in Precision Mass Production of Variable Resistors

Section Meetings

ALBUQUERQUE-LOS ALAMOS

"Time Conversion Pulse Height Analyzers," by R. J. Watts, Los Alamos Labs., Univ. of California; February 18, 1955.

"Mathematics of Boards, Panels and Committees," by Dr. J. W. McRae, Sandia Corp., and "Problems Encountered in Phase Measurements," by Claxton Foster, Technology Instruments Corp.; January 20, 1955.

ATLANTA

Tapescript: "Method for Time or Frequency Compression-Expansion of Speech," by Messrs. Everitt, Fairbanks and Jaeger, University of Illinois; January 21, 1955.

BALTIMORE

"Transmission Lines for Millimeter Waves," by Dr. D. D. King, Johns Hopkins Radiation Lab.; February 9, 1955.

BEAUMONT-PORT ARTHUR

"Recent Advances in the Reproducing Art," by A. M. Wiggins and H. T. Souther, Electro-Voice, Inc.; January 17, 1955.

CEDAR RAPIDS

Installation of officers; January 29, 1955.

CLEVELAND

"Teaching Old Dogs New Tricks in Electronic Instrumentation," by W. C. Moore, Boonton Radio Corp.; January 27, 1955.

CONNECTICUT VALLEY

"A Resistor Network for Simulating Geological Conditions," by J. H. Baker, Schlumberger Well Surveying Corp., and "The Solution of Simultaneous Equations on a Differential Analyzer," by G. H. Martin; January 20, 1955.

DAYTON

"Air Defense," by Dr. A. G. Hill, MIT Lincoln Laboratory; February 3, 1955.

DENVER

"Transcontinental Microwave Radio Relay Systems," by E. L. Broders and F. D. Borstadt, both of American Tel. and Tel. Company; December 10, 1954.

"Synthesis of Aperture Antennas," by Dr. C T. Johnk, University of Colorado; January 14, 1955.

DES MOINES-AMES

"The Effect of Utilization of Engineering Manpower," by F. D. Agathe, Allis Chalmers, February 15, 1955.

"Manpower Development," by George Downing, General Electric Company; January 18, 1955.

DETROIT

"Principles of Color Television," by C. N. Hoyler, R.C.A.; January 26, 1955.

"Controls that Think and Act Automatically," by C. R. Molenaar, General Electric Company; February 18, 1955.

EL PASO

"Field Measurements of Guided Missiles," by Lt. Col. W. J. Bromley, Flight Determination Lab., WSPG, N. Mex.; January 27, 1955.

EMPORIUM

"The 600 Mill Line of T.V. Tubes," by A. W. Peterson, Sylvania Electric Products, Inc.; January 25, 1955

EVANSVILLE-OWENSBORO

"Application of IBM Equipment to Engineering and Statistical Problems," by Dr. P. Sterbenz, I.B.M.; February 9, 1955.

(Continued on page 94A)

Section Meetings

(Continued from page 92A)

Fort Wayne

"Telemetering Challenge, 1955," by W. J. Mayo-Wells, Johns Hopkins University; February 3, 1955.

"Illustrating the Technical Report," by Adrian TerLouw, Eastman Kodak Company; February 10, 1955.

Hamilton

"Microwave Techniques," by Arthur Dinnin, Bell Telephone Co.; January 10, 1955.

Hawaii

"Inspection Tour and Demonstration of CAA Airport Surveillance Radar, ASR-2," by Frank Kadi, Civil Aeronautics Administration; February 10, 1955.

Houston

"Electrons, Engineers and Education," by Dr. J. D. Ryder, President, IRE; February 8, 1955.

Huntsville

"The Southern Research Institute, Its Objectives and Functions, and Summary of Its Projects," by Sabert Oglesby, Southern Research Institute; December 16, 1954.

"Analysis of Data Recording Systems," by T. L. Greenwood, Redstone Arsenal; January 26, 1955.

Inyokern

"Low Noise Travelling Wave Tubes," by Dr. D. A. Watkins, Stanford University; December 31, 1954.

Ithaca

"Electronics and Medicine," by Dr. E. B. Wright, University of Rochester; February 1, 1955.

Little Rock

"Recent Amendments of F.C.C. Rules and Standards Affecting Color Television and AM Broadcasting," by J. G. Roundtree, consulting radio engineer; February 8, 1955.

"Electronics in the Computer Systems," by R. R. Pierce, I.B.M.; January 11, 1955.

London

"The Principles of Color Television," by C. N. Hoyler, RCA Victor Ltd.; January 27, 1955.

"Primary Standard and the Radio Engineer," by Dr. J. T. Henderson, Director, IRE Region 8; February 10, 1955.

Long Island

"Measurements at DC and Power Frequencies," by John H. Miller, Weston Electrical Instrument Corp.; January 27, 1955.

"Basic Audio and Radio-Frequency Measurements," by W. R. Thurston, General Radio Company; February 3, 1955.

"Computers," by J. Johnson, I.B.M.; February 8, 1955.

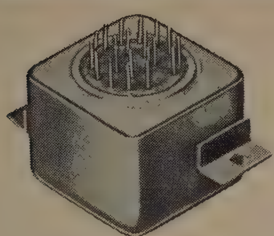
"Oscillography," by W. G. Fockler, A. B. DuMont and A. A. Emmerling and H. H. Chamberlain, General Electric Company; February 10, 1955.

Los Angeles

"Electronics and Mathematical Analysis in Business Operations," by Dr. Simon Ramo, Ramo Wooldridge Corp.; January 11, 1955.

"Instrumentation in Smog Research," by Dr. F. Littman, Pasadena Lab. of S.R.I., "Surface Wave Antennas," by Dr. R. S. Elliott, Hughes Aircraft, and "New Developments in Traveling Wave Tubes and Backward-Wave Tubes," by Dr. D. A. Watkins, Stanford University; February 1, 1955.

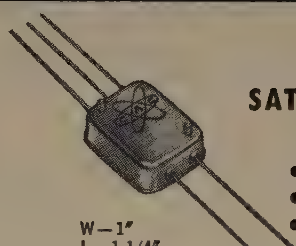
(Continued on page 96A)



Depicted—6KC 100 Watt Unit
Less than 1.65 cubic inches

POWER TRANSFORMERS

Range—400-6000 cps
Efficiency—up to 95%
Wattage—6mw-200 watts
Temperature—-55 to +155° C.



W—1″
L—1 1/4″
H—15/32″

SATURABLE REACTORS

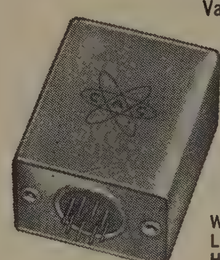
Applications
- Servo Systems
- Data Telemetering
- Remote Frequency Control

Illustrated—High Frequency Reactor Tuned by Varying D. C. Current

W—3/4″
L—3/4″
H—5/16″

PULSE TRANSFORMERS

Pulse Width—.2-50 microseconds
Rise Time—from .03 microseconds
- Blocking oscillator
- Pulse coupling
- Toroidal construction

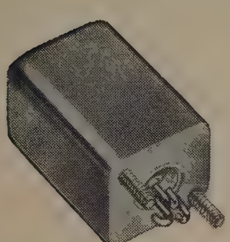


MAGNETIC AMPLIFIERS

Wattage (output) .5-200 watts
Response—1 cycle up

W—1 1/4″
L—1 3/4″
H—2 5/32″

Illustrated—Auto Pilot Application for Printed Circuit Mounting



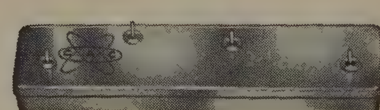
W—23/32″
L—23/32″
H—11/16″

Illustrated 4KC Band Pass

SUB-MINIATURE FILTERS

For Chassis Mount

Frequency—2.3-35Kc
Impedance in—600-10K Ohms
Impedance out—Grid
- Hermetic Sealed
- Temperature Compensated
- Internal D.C. Isolation
- Balanced or Unbalanced
- Military Specifications



SUB-MINIATURE TUNED CIRCUITS

For Printed Circuit Applications
- Multiple Tuned Transformers
- Delay Lines
- Tuned Circuits

W—1″
L—4 1/4″
H—7/16″

FOR ADDITIONAL INFORMATION CONTACT

COMMUNICATION ACCESSORIES COMPANY

HICKMAN MILLS, MISSOURI • PHONE KANSAS CITY, SOUTH 5528

3-55/1.0

Section Meetings

(Continued from page 94A)

Miami

Taped recording: "Principles, Design and Operation of Color Television," by John Wentworth, RCA, and question and answer forum conducted by C. X. Castle, WGBS-TV; January 28, 1955.

New Orleans

Colorcast and demonstration of the color camera and monitoring equipment of WDSU; January 30, 1955.

"Electrons, Engineers and Education," by John D. Ryder, President, IRE; February 7, 1955.

New York

"The Past, Present and Future of Magnetic Recording," by J. S. Boyers, The National Company; January 5, 1955.

"Limitations on the Production and Measurement of Very Low Pressure," by D. Alpert, Westinghouse Research Labs.; February 2, 1955.

North Carolina-Virginia

"Recent Developments in Raydist Systems," by A. L. Comstock, Hastings Instrument Company; February 18, 1955.

Northern New Jersey

"Highlights of Antenna Lore," by E. A. Laport, RCA International; February 9, 1955.

Oklahoma City

"AC Network Calculators," by Miles Maxwell Westinghouse Electric Corp.; February 16, 1955.

Ottawa

"Recent Advances in Microwave Tubes," by Dr. J. R. Pierce, Bell Telephone Labs.; January 27, 1955.

Philadelphia

"Electronic Instrumentation for the Brookhaven Nuclear Reactor," by J. Binns, Brookhaven National Laboratory; January 13, 1955.

"Operation Dew Line," (Distant Early Warning) by V. B. Bannall, Western Electric Company; February 2, 1955.

Phoenix

"Smog" (included movie "The City That Disappears") by Dr. Beardsley Graham, Stanford Research Institute; January 21, 1955.

"The Mission and Technical Philosophy of the Army Electronic Proving Ground," by Dr. Robert Burns, Fort Huachuca; February 18, 1955.

Portland

"Bonneville Power Administration Microwave Communication and Load Dispatching Systems," by E. Warchol and L. W. Danilson; January 20, 1955.

"High Fidelity and Speaker Enclosures," by J. C. Riley, Iron Fireman-Electronics Div.; February 16, 1955.

Rome-Utica

"Information Theory," by Dr. Stanford Goldman, Syracuse University; February 3, 1955.

Sacramento

"Locked Oscillators," by L. S. Cutler, Gertsch Products Corp.; February 11, 1955.

St. Louis

"Global Communications in the Air Force," by by R. P. Mueller, Scott Air Force Base; December 16, 1954.

"The Iatron Variable Persistence Cathode Ray Tube," by Harold Jacobsmeier, Emerson Electric Corp.; January 27, 1955.

(Continued on page 99A)

Section Meetings

(Continued from page 96A)

SAN ANTONIO

"Digital Computers," by W. M. Aamoth and W. Robert Hydeman, Remington Rand, December 16, 1954.

"Recent Improvements in the Reproducing Art," by A. M. Wiggins and H. T. Souther, Electro-Voice, Inc.; January 20, 1955.

"High High Frequencies (Generation of Millimeter Waves)," by Dr. J. D. Ryder, President, IRE; February 9, 1955.

SCHENECTADY

"Electrons, Engineers and Education," by Dr. J. Ryder, President, IRE; January 21, 1955.

SYRACUSE

"The Psychological Matrix Rotation Computer," by G. T. Jacobi, General Electric Company; February 7, 1955.

TORONTO

"The Automatic Switching of Long Distance Calls," by F. H. Western; January 17 .1955.

"Problems of Television Receiver Manufacturing in Canada," by R. Munitz, Canadian Westinghouse Company; January 31, 1955.

Students' Night: "Electrical Characteristics of Human Nervous Systems," by L. D. Pengelly, "Magnetic Recording," by J. F. Hanson and "Binary Numbers and Boolean Algebra," by W. F. Elliott, all students; February 10. 1955.

TULSA

"Characteristics of Mechanical Filters," by Bob Loming, Collins Radio Corp.; January 20, 1955

TWIN CITIES

"A Case History of a Booster Station for Improved UHF TV Reception," by W. C. Morrison, RCA Labs.; January 20, 1955.

VANCOUVER

"Automatic Computers as Applied to Training Devices," by Dr. E. V. Bohn, University of British Columbia; January 17, 1955.

WASHINGTON, D. C.

"Information Storage in the Protein Molecule," by Dr. George Gamow, George Washington University; February 14, 1955.

WILLIAMSPORT

"A General Discussion of Various Color TV Picture Tubes," by Dr. H. B. Law, RCA; January 19, 1955.

SUBSECTIONS

AMARILLO-LUBBOCK

General meeting; January 13, 1955.

BERKSHIRE COUNTY

General meeting; February 2, 1955.

BUENAVENTURA

"Raydac Computer at Point Mugu," by Dr. L. Fein, Computer Control Company; January 13, 1955.

ERIE

Demonstration lecture on "The Principles of Color Television," by C. N. Hoyler, RCA: January 24, 1955.

LANCASTER

"Control of Costs of Research and Development Projects," by H. J. Finison, National Pneumatic Company, Inc.; January 12, 1955.

MID-HUDSON

"High-Voltage Equipment," by Dr. Victor Wouk, Beta Electric Corp.; February 1, 1955.

(Continued on page 101A)

Section Meetings

(*Continued from page 99A*)

MONMOUTH

"Color Television," talk and demonstration by I. E. Lempert, Westinghouse Electric Corp.; February 2, 1955.

ORANGE BELT

"General Considerations and Mathematical Development of Reliability in Electronic Systems," by J. H. Parsons and A. Yeiser, Hughes Aircraft Company, and "Your IRE—Let's Discuss It," by John Byrne, Motorola Research Lab.; February 9, 1955.

TUCSON

"Etched Circuitry Processes," by G. McLaughlin and Dr. L. Ott, both of Hughes Aircraft Company; December 16, 1954.

Professional Group Meetings

AERONAUTICAL AND NAVIGATIONAL ELECTRONICS

The Dayton Chapter of the Professional Group on Aeronautical and Navigational Electronics met December 2 at the Engineers Club, Chairman Paul Wiegert presiding. Kenneth C. Jordan, Monsanto Chemical Company, presented a paper on "Nuclear-Powered Batteries," in which he outlined the history of atomic batteries from 1878, the time of Faraday's first experiments with radium as a source of electrical power, and described the technical composition and application of the battery. The paper provoked much discussion from the floor.

AUDIO

The Houston Chapter of the Professional Group on Audio met at the Humble Research Center on January 18. Chairman Walter J. Greer presided. A paper on "High-Fidelity Components" was delivered by A. M. Wiggins and Howard T. Souther, Vice President of Engineering and Sales Manager of Electro-Voice, Incorporated.

The meeting of the Cleveland Chapter, at which Chairman Herbert H. Heller presided, was held at WDOK-Cleveland Recording Company Studios on January 20. E. M. Jones, an engineer with the Baldwin Company, presented a paper on "How Much Distortion Can You Hear?"

Hoyt Westcott presided at the meeting of the Albuquerque-Los Alamos Chapter, held on January 17 at the Radiation Therapy Building, Lovelace Clinic, Albuquerque. Ben Sanders, of Sanders Associates, gave a paper on "Ampex Stereophonic System and Ampex 600 Design," and demonstrated the system.

(*Continued on page 102A*)

Professional Group Meetings

(Continued from page 104A)

Automatic Control

On January 13, The Dallas-Fort Worth Chapter of the Professional Group on Automatic Control met at the Engineering Building, Southern Methodist University. John A. Green, Section Chairman, spoke briefly on IRE general policies and plans. At this meeting, the following officers were elected: Chairman—F. W. Tatum, Head of Electrical Engineering Department. Southern Methodist University; Vice-Chairman—A. R. Teasdale, Chief of Electronic Design, Temco Aircraft Corporation, Dallas; Secretary—H. W. Prier, Lead Systems Design Engineer, Chance Vought Aircraft, Dallas.

Broadcast Transmission Systems

George M. Ives presided at the January 21 meeting of the Chicago Chapter of the Professional Group on Broadcast Transmission Systems. A paper on "The Chromacoder" was presented by Pierre H. Boucheron, Jr., Project Engineer, General Electric Company, Syracuse, N. Y. The Chromacoder is a device for changing a field-sequential color-television signal into a N.T.S.C. color TV signal. Mr. Boucheron outlined its structure and use.

Communications Systems

The Washington, D. C., Chapter of the Professional Group on Communications Systems met on January 26 at the Auditorium of the Potomac Electric Power Company. William C. Boese, Chairman, presided. The speaker was Haraden Pratt, Secretary of the Institute of Radio Engineers. Mr. Pratt spoke on the "Birth and Growth of Telecommunications," covering the highlights of the growth of telecommunications, and describing the vicissitudes of such early pioneers in the field as Morse, Collins, and Field. Mr. Pratt's address reflected his intimate knowledge of the history of the early wire, cable, and radio telecommunications organizations and the personalities who directed it.

Component Parts

M. P. Feyerherm presided at the Sepber 28 meeting of the Philadelphia Chapter of the Professional Group on Component Parts, held at the Engineers Club of Philadelphia. Alex Bezat, of the Minneapolis-Honeywell Company, spoke on "Electric Insulation at Elevated Temperatures." Mr. Bezat described the Minneapolis-Honeywell program for classification of insulating materials according to useful temperature range, and discussed specific materials in some detail. He also submitted proposals for new industry-wide temperature classes and new test methods.

The Dayton meeting was held at the Engineers Club of Dayton on December 2, with Floyd E. Wenger presiding. A paper on "Computer Components" was pre-

(Continued on page 104A)

COMMON CHARACTERISTICS OF ALL TYPE 2131 GEARED MOTOR GENERATOR UNITS

O.D. of Case............1.000 inch
Case Length............3.301
Weight............7.5 ounces
Frequency............400 cycles

No. of Poles (Motor)............6
*No Load Speed (Min.)............6500 rpm
Rotor Inertia............1.1 gram-cm²

*Motor Speed at input to gear train

NEW
integral gear head in small servo motors

OUTSTANDING FEATURES OF TYPE 2131 GEARED MOTOR GENERATOR

- New methods of manufacture result in high efficiency
- High torque to inertia ratio to give fast response
- Available for 115 volt—115 volt two phase or single ended tube operation
- High impedance winding for direct plate to plate operation available
- High generator output voltage with excellent signal to noise ratio
- Zero degree phase shift in generator
- All metal parts corrosion resistant
- Extremely wide operating temperature range

Other models of one inch O.D. units

TYPE NO.	DESCRIPTION
2103	Induction Motor
2101	Geared Induction Motor
2028	Motor Generator

A new line of units has been added to the Kollsman "Special Purpose Motors" family combining precision machining, advanced electrical design and the latest in new materials. An unusual feature of the new line is the integral gear head unit. Contained within a single case is the gear train and motor; or gear train, motor and generator. Gear ratios as high as 300:1 can be supplied.

This new line consists of Induction Motors and Induction Generators supplied separately or combined in a single case one-inch in diameter. The new motors have been designed to give the maximum torque per watt ratio with the minimum rotor inertia. The generators have been designed to give the maximum output voltage with the minimum residual voltage and phase shift.

One of the principal features of the Kollsman "Special Purpose Motors" is the interchangeability of parts which permits numerous electrically different combinations of motor and generator windings within the same case.

INPUT PER PHASE ONLY 1.8 WATTS
ELECTRICAL CHARACTERISTICS
OF TYPICAL TYPE 2131 GEARED MOTOR GENERATORS

	MOTOR					GENERATOR		
TYPE NO.	EXCITATION FIXED	EXCITATION CONTROL	INPUT PER PHASE	STALL TORQUE	Theoretical Acceleration At Stall	EXCI-TATION FIXED	INPUT	OUTPUT PER 1000 rpm
2131-0411110	26	26	2.3	0.4	25600	26	1.8	.51
2131D-0412120	26	26	4.0	0.6	38500	26	2.2	.68
2131D-0413120	26	26	1.8	0.3	19200	26	2.2	.68
2131-0460600	115	115	4.0	0.6	38500	115	2.6	1.00
2131-0463600	115	55	4.0	0.6	38500	115	2.6	1.00
2131-0470600	115	P-P	4.0	0.6	38500	115	2.6	1.00
	volts	volts	watts	Oz-n	rad/sec²	volts	watts	volts

Latest catalog and/or complete specification drawings will be sent upon request.

kollsman INSTRUMENT CORPORATION

80-16 45th AVE., ELMHURST, NEW YORK • GLENDALE, CALIFORNIA • SUBSIDIARY OF *Standard* COIL PRODUCTS CO. INC.

Professional Group Meetings

(Continued from page 102A)

sented by Gilbert Devy of the Sprague Electric Company. Mr. Devy described two assembled components, a flip-flop circuitry unit, and a phase-shift device. He stressed the requirements for utmost reliability and stated the aim of satisfying RETMA and military standards wherever such requirements have been formalized or specified.

Electron Devices

The San Francisco Chapter of the Professional Group on Electron Devices met at Stanford University on January 5. Chairman S. F. Kaisel presided. G. Alpert, Manager of the Physics Department Research Laboratory of Westinghouse Electric Corporation, delivered a paper on "Ultra-High Vacuum Techniques."

Engineering Management

On January 6 the Dayton Chapter of the Professional Group on Engineering Management met at the Engineers Club under the Chairmanship of Elbert W. Piety. Raymond W. Crowley spoke on "The Rights of Employers in the Inventions of Employees." He traced the origin of common law on such invention rights, and outlined the present position on patent ownership, "shop rights," employer-employee contracts, and the establishment, by Executive Order No. 10096, of a uniform patent policy for the government.

Electronic Computers

The Philadelphia Chapter of the Professional Group on Electronic Computers met on January 18 at the Benjamin Franklin Center for Physics, Astronomy, and Mathematics of the University of Pennsylvania. T. H. Bonn was the presiding officer. A paper on "Automatic Programming for Digital Computers" was presented by Dr. John W. Mauchly, Eckert-Mauchly Division, Remington-Rand, Incorporated. Dr. Mauchly discussed the probable development of programming, especially automatic coding, and gave the presently known types of automatic coding techniques, i.e., compiler techniques, generator techniques, interpretive techniques, and analytic techniques.

The Dallas-Fort Worth Chapter met on November 30 at Magnolia Petroleum Company, Field Research Laboratories. Louis B. Wadel occupied the Chair. Lynn D. Mullins and W. F. Baldwin, of the Magnolia Petroleum Company, demonstrated an analog computer used for finding the best method of recovering petroleum from an oil field of known or assumed characteristics. From a four-year history of the field, including logging information from field engineers, prediction of future production under different rates and pressures may be made for a two-year period with an accuracy of five to ten per cent.

(Continued on page 107A)

Professional Group Meetings

(Continued from page 104A)

On January 25, the chapter met again in Fort Worth with D. J. Simmons presiding. On this occasion L. E. Heizer, an aerophysics engineer with Convair, presented a paper on a "Handbook of Analog Computer Circuits and Techniques." Topics discussed in the paper included basic problem set-up procedures, voltage scale factors, time-scale changes, tables of computing circuits, machine applications and limitations, and problem check-out procedures. A sample airplane autopilot problem is set up to illustrate and integrate the various sections of the manual.

At Massa Hall, Hayward, California, the San Francisco Chapter held a meeting on November 16, 1954. Dr. Jerre Noe conducted the meeting. "A Symposium—Computer Maintenance" was presented by Arnold Karpin, Lou Fine, and Preston Hamilton.

The Akron Chapter met on December 20 at Goodyear Hall, with Chairman C. D. Morrill presiding. Professor Robert M. Howe of the University of Michigan presented a paper on "Choosing Computer Components for Large-Scale Simulators." Dr. Howe discussed the type and scope of equations involved in several large-scale simulations, the computer-component requirements for solving these equations, and the relative merits of ac and dc differential analyzers.

Information Theory

The Albuquerque-Los Alamos Chapter of the Professional Group on Information Theory met on January 12 at the University of New Mexico. C. H. Bidwell presided. Dr. B. L. Basore spoke to the group on "A Statistical Theory of Target Detection by Pulsed Radar."

With Dr. D. B. Duncan presiding, the Los Angeles Chapter met at the Institute for Numerical Analysis on December 9. There were two speakers. "Passage of Non-Gaussian Noise through Linear Systems" was the name of the paper presented by Dr. Jack Heilfron of Ramo Wooldridge Corporation. Ralph Deutsch, Hughes Aircraft Company, spoke on "A Method of Wiener for Noise through Non-Linear Devices."

Microwave Theory and Techniques

On January 19 the Northern New Jersey Chapter of the Professional Group on Microwave Theory and Techniques held an organizational meeting at which the following officers were elected: Chairman, T. N. Anderson; Vice-Chairman, R. E. White; Secretary, S. Levine; Program Chairman, R. C. McVeety, Jr. A paper, "A Display of X-Band Impedance on an Oscilloscope," was presented by H. L. Bachman of Wheeler Laboratories.

The Buffalo-Niagara Chapter met on October 27 at the University of Buffalo. Dwight Caswell, President of Cascade Research Corporation, spoke to the group on

(Continued on page 108A)

Professional Group Meetings

(Continued from page 107A)

"Ferrites for Microwave Applications." On December 15 the group met jointly with the Buffalo-Niagara Section. "An Airborne Weather Radar for Civil Aircraft," was the subject presented by K. F. Molz of Bendix Radio.

Nuclear Science

The Oak Ridge Chapter of the Professional Group on Nuclear Science met on October 20 with H. E. Walchli presiding J. E. Broyles, Chief Engineer of Station WTSK, spoke on "Some Operational Aspects of Television Stations." On November 17 the Oak Ridge Chapter met again. W. H. Lee, Chairman of the AIEE Oak Ridge Section, presided. Dr. Robert M. Page, Naval Research Laboratory, presented "Detection of Ice and Hurricanes by Radar."

The Connecticut Valley Chapter met on December 14 at Christopher Columbus Auditorium. Three films were presented to the group: "Operation Greenhouse," "Operation Crossroads," and "A Tale of Two Cities."

Telemetry and Remote Control

The Los Angeles Chapter of the Professional Group on Telemetry and Remote Control met on January 18 at the IAS Building. R. E. Rawlins presided and there were two speakers. F. E. Bryan of Douglas Aircraft spoke on "Telemetering of Millivolt Level Signals by PWM-FM," and G. F. Anderson of Radiation, Incorporated, discussed "A High Capacity PTM-AM Telemeter." A summary of telemetering objectives at Convair was presented by E. L. Watkins, Consolidated-Vultee Aircraft Corporation.

Vehicular Communications

The Detroit Chapter met on January 19 at the Engineering Society of Detroit. A. B. Buchanan presided and T. P. Rykala, Michigan Consolidated Gas Company, discussed the company's communication problems as related to its growth.

IRE People

A number of changes in the staff of the Antenna Laboratory at the Ohio State University have been made recently. **T. E. Tice** (S'46–A'50) has been made Supervisor of the Antenna Laboratory. Dr. Tice received the Ph.D. degree from Ohio State in 1951 and since last spring has been Acting Supervisor of the laboratory; he replaces **V. H. Rumsey** (SM'50). **C. T. Tai** (S'44–A'48–SM'51) has joined the Antenna Lab-

(Continued on page 110A)

I R E People

(Continued from page 108A)

oratory and been appointed Associate Professor in the Department of Electrical Engineering. Dr. Tai received the Ph.D. degree from Harvard in 1947 and comes to Ohio State from the Stanford Research Institute. Professors **J. D. Kraus** (A'32–M'43–SM'43–F'54), and **G. E. Mueller** (S'39–A'41–SM'46) of the Department of Electrical Engineering are consultants to the Antenna Laboratory. **R. G. Kouyoumjian** (A'53) continues on the Antenna Laboratory staff and also joins the Department of Electrical Engineering as Assistant Professor.

❖

George Haydu, General Manager of the Haydu Brothers Division, Burroughs Corporation, has announced the appointment of **Victor Le Gendre** (M'53) as Chief Engineer of the Plainfield, New Jersey plant.

Victor Le Gendre

Mr. Le Gendre came to Haydu from Chatham Electronics Corporation where he was Design and Development Engineer. In the interim between the war years and his experience with Chatham Electronics Corporation, Mr. Le Gendre was with Tung-Sol Electric, Inc., for five years and National Union Electric for a year and a half. Prior to United States' entry in World War II, Mr. Le Gendre volunteered for the Canadian Army and saw three and a half years of service with the Anti-Aircraft Artillery; he attained the rank of Captain.

Although born in the United States, he was educated in Canada, where he received the B.A. degree from Laval University in Quebec City and the B.S. from University of Ottawa where he taught physics and chemistry for three years. Mr. Le Gendre holds Patent No. 2,654,401 on fine pitch grid winding and has another patent pending on grid winding structures.

❖

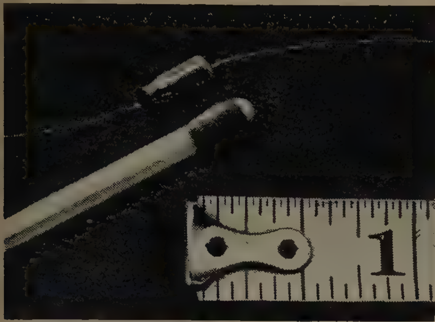
The appointment of **G. L. Haller** (A'28–H'36–SM'43–F'50) as Manager of the Laboratories Department of General Electric Company's Electronics Division has been announced. Dr. Haller was Dean of the College of Chemistry and Physics at Pennsylvania State University prior to his appointment and, for the past two years, was also a consultant to the Laboratories Department.

G. L. Haller

Dr. Haller was born in Pittsburgh, Pa.

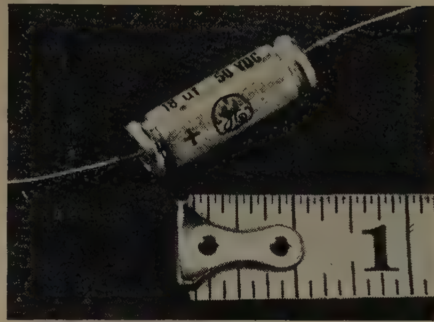
(Continued on page 112A)

CAPACITORS by General Electric



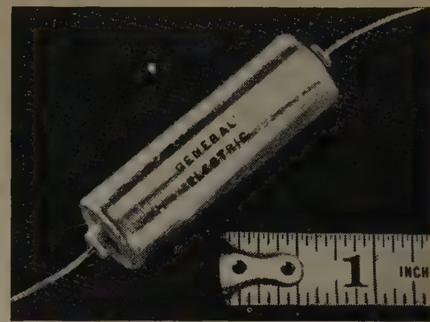
MICRO-MINIATURE

For low voltage d-c miniaturized electronic equipment (hearing aids, walkie-talkies, paging systems). Ideal for transistorized assemblies. **Ratings** 1-8 uf at 4 v. d-c, 1 uf at 8 v. d-c, 0.5 uf at 16 v. d-c. **Tolerance** −0 to +200%. **Temp. range** −20 to +50° C. BULLETIN GEA-6065.



TANTALYTIC*

For electronic equipment requiring small size, low leakage current, long shelf life, wide temperature range. Plain or etched foil, and polar or non-polar types, suitable for a-c or d-c. **Ratings** 0.25−580 uf, 3.75−150 v. **Tolerance** ±20% (plain foil), −15 to +75% (etched). **Temp. range** −55 to +85° C. BULLETIN GEC-808.



METAL-CLAD TUBULAR

For d-c uses where reliability under severe operating conditions is required (military electronic equipment). **Ratings** 0.001−1 uf at 100, 200, 300, 400 and 600 working v. d-c. (Can be applied to a-c circuits with adequate derating.) **Tolerances** ±5, ±10, or ±20%. **Temp. range** −55 to +125° C. BULLETIN GEC-987.

PERMAFIL-IMPREGNATED

Designed to meet requirements of MIL-C-25A, characteristic K specifications, and are suitable for high-temperature operation. **Ratings** 0.05−1 uf at 400 v. d-c. **Tolerance** ±10%. **Temp. range** −55 to +125° C. BULLETIN GEC-811.

STANDARD COMMERCIAL

For motors, filters, communication equipment, luminous-tube transformers, industrial control. **Ratings** dual rated units (a-c or d-c) rated at 0.01−50 uf, at 236-660 v. a-c, 400-1500 v. d-c. Single rated units also available. **Tolerance** ±10%. **Temp. range** −55 to +85° C. BULLETIN GEC-809.

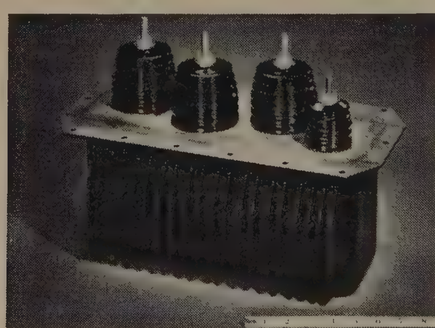
DRAWN-OVAL

For air conditioning and refrigeration equipment, fluorescent lamp ballasts, business machines, voltage stabilizers. Single, dual or triple-section types. **Ratings** 1−20 uf at 236-660 v. a-c, and 1-15 uf at 600-1500 v. d-c. **Tolerance** ±10%. **Temp. range** −30 to +70° C. BULLETIN GEA-5777.

**Reg. trademark of General Electric Company.*

ENERGY STORAGE

For use in high magnetic fields and high intensity arc discharge. **Ratings:** may be built as high as 2000 joules (watt-seconds). **Tolerance** ±10%. BULLETIN GEA-4646.



NETWORK

For guided missiles, aircraft, radar equipment. **Ratings:** built to user specifications. **Temp. range** −55 to +125° C, or to user specifications. BULLETIN GEA-4996.

NOTE: All capacitance tolerances are given at +25° C.

SEND COUPON BELOW for complete information about G-E capacitors.

General Electric Co.
Section E442-25
Schenectady 5, N.Y.

Please send me capacitor bulletins checked below.

- ☐ GEA-4646
- ☐ GEA-4996
- ☐ GEA-5777
- ☐ GEA-6065
- ☐ GEC-808
- ☐ GEC-809
- ☐ GEC-811
- ☐ GEC-987

Name..............................

Position..............................

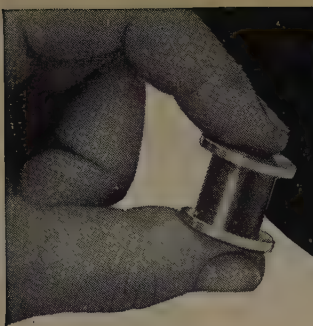
Company..............................

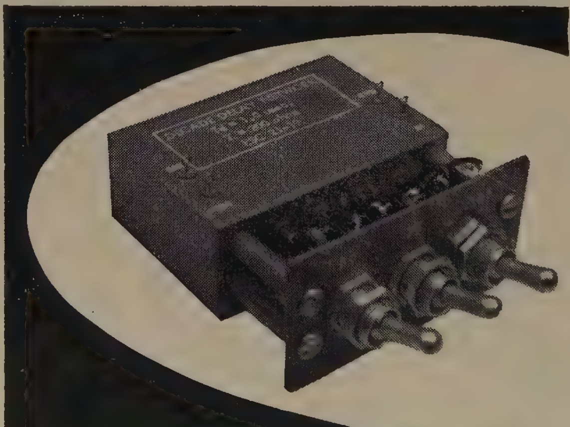
Address..............................

City.............. **Zone**...... **State**..........

Progress Is Our Most Important Product

GENERAL ELECTRIC





I R E People

(*Continued from page 110A*)

He was graduated from Mercersburg Academy in 1924, and received four degrees from Pennsylvania State University: B.S. in e.e. in 1927, electrical engineer in 1934, M.S. in e.e. in 1935, and Ph.D. in physics in 1942.

He was a radio engineer for Westinghouse Electric and Manufacturing Company, in East Pittsburgh from 1927 to 1929, and audio engineer for E. A. Myers & Sons in Pittsburgh from 1929 to 1933, before returning to Penn State as a graduate assistant. He remained at the university until 1935 when he became a radio engineer at Wright Field for the War Department. From 1942 until 1946, Dr. Haller served in the Signal Corps and later the Air Corps, holding the rank of colonel. For his service, he was awarded the Legion of Merit. He became assistant dean of the College of Chemistry and Physics at Penn State in 1946, and a year later was appointed dean.

Dr. Haller is a member of the Signal Corps Research and Development Advisory Council, the Army Electronic Proving Ground Advisory Council, and the Technical Advisory Panel on Electronics for the Assistant Secretary of Defense. He is a fellow in the American Physical Society, an associate in the Institute of Aeronautical Engineers, and a member of the American Institute of Electrical Engineers, the American Society for Engineering Education, the Franklin Institute, the Newcomen Society of England, Sigma Xi, Tau Beta Pi, Eta Kappa Nu, Sigma Pi Sigma, Phi Lambda Upsilon, Phi Eta Sigma, Pi Mu Epsilon, Alpha Epsilon Delta.

❖

The appointment of **R. G. E. Hutter** (SM'46–F'54) as Manager of the Physics Laboratory of Sylvania Electric Products Incorporated has been announced. Formerly Manager of the Physical Electronics Branch of the Physics Laboratories, Dr. Hutter has been with the Sylvania Laboratories on Long Island since November, 1944. As a research physicist he has been associated with the field of electron optics, especially the design of cathode ray and traveling wave tubes.

R. G. E. HUTTER

Born in Berlin, Dr. Hutter was a graduate student in physics and mathematics at the University of Berlin from 1930 to 1936. From 1936 to 1938 he was a research physicist in the transmitter laboratories at Telefunken, G.M.B.H. Following that he was Chief Engineer of radio station KZIB, Manila, Philippine Islands. From 1940 to 1941 he was a graduate student in com-

(*Continued on page 114A*)

IRE People

(Continued from page 112A)

munication engineering and physics at Stanford University; in 1941 he became a research associate in the Division of Electron Optics; and in 1944 he received the Ph.D. degree there.

Dr. Hutter is a member of the American Physical Society and of Sigma Xi. He is an Adjunct Professor at the Polytechnic Institute of Brooklyn.

❖

P. C. Sandretto (A'30–M'40–SM'43–F'54), Brigadier General U. S. Air Force Reserve, has been named an Assistant Vice-President of Federal Telecommunication Laboratories, Nutley, New Jersey, a division of International Telephone and Telegraph Corporation. A technical director of FTL, he will act as general coordinator for military research and development projects.

P. C. Sandretto

General Sandretto joined the IT&T System in 1946 and held a number of positions in the aeronautical radio research and development activities of the corporation. He was made an Assistant Technical Director of the laboratories in 1948 and was promoted to Technical Director in 1953. Prior to his association with IT&T, he was a member of the technical staff of Bell Telephone Laboratories where he helped design some of the first radio equipment for commercial aircraft in the United States. During World War II, he won recognition for his services with the U. S. Air Force in connection with the planning and establishing of military electronics in the Pacific area.

A writer on aeronautical radio engineering, General Sandretto has served on committees of the Radio Technical Commission for Aeronautics since its inception in 1935. He is a member of the Institute of Navigation, and an associate member of the Institution of Electrical Engineers.

❖

A. E. Abel (A'43–SM'45) has been named Director of Engineering and Research for the Bendix Radio Communications Division of the Bendix Aviation Corporation. In his new post he will direct the activities of the division's 1900 engineering employees engaged in design, test and inspection, research and development, and field engineering work. Mr. Abel formerly served as Assistant Director for more than two years.

A native of Chicago, he was graduated from the Oak Cliff High School in Dallas, Texas, and attended the University of Illinois from 1926–34. He was awarded a Bachelor of Science and a Master of Sci-

(Continued on page 117A)

IRE People

(Continued from page 114A)

ence degree from that university, both in electrical engineering. During his last two years there he was a special test assistant.

From 1935–1936 Mr. Abel was a Project Engineer for the RCA Manufacturing Company, in Camden, New Jersey, and worked primarily with aircraft transmitters. In 1937 he joined the Bendix Radio Corporation, predecessor of the present division and has been with the organization ever since.

At the conclusion of World War II, Mr. Abel received a Certificate of Commendation from U. S. Navy, Bureau of Ships, and a Certificate of Appreciation from the War Department for outstanding service during the war in radar, communication development, and production.

❖

A. B. Bronwell (A'39–SM'43) has been elected to succeed Alvin E. Cormeny as President of Worcester Polytechnic Institute. On the Northwestern University electrical engineering faculty since 1937, Dr. Bronwell during World War II organized and supervised the Army Signal Corps school in radio and ultra high frequencies, located at Northwestern. Executive secretary of the American Society for Engineering Education for the past seven years, in 1951, at Gen. Matthew B. Ridgway's invitation, he visited Japan as a member of a commission on engineering education.

❖

The appointment of **N. H. Mageoch** (M'53) to the position of Vice-President for Operations at Daystrom Instrument has been announced. In his new position, he will direct certain phases of product engineering and all activities related to industrial engineering, manufacturing engineering, quality control, production control, assembly, fabrication and installation.

N. H. Mageoch

Mr. Mageoch, a graduate of Drexel Institute with post graduate work in applied science at University of Pennsylvania, came to Daystrom Instrument in 1951. He was made Chief Engineer in 1952, Director of Research and Engineering in 1953, and in 1954 Vice-President of Research and Engineering. In this position he directed industrial engineering, equipment installation, inspection and test and the firm's Pilot Plant operation.

Mr. Mageoch is a member of the American Institute of Electrical Engineers, the American Ordnance Association, the Institute of Radio Engineers, and the Association of Computing Machinery.

(Continued on page 118A)

IRE People

(Continued from page 117A)

A. G. Clavier (M'30–F'39), formerly a Technical Director, has been made an Assistant Vice-President of Federal Telecommunication Laboratories, a division of International Telephone and Telegraph Corporation. Mr. Clavier joined the IT&T System in 1929 as a member of the engineering staff of Laboratoire Central de Telecommunications, an IT&T associate in Paris, and later became assistant director of the company. He was named an Assistant Technical Director of FTL in 1946 and a Technical Director in 1952.

A. G. CLAIEVR

The new Assistant Vice-President is recognized in connection with the development of microwave communication. He was associated with the first successful demonstration of microwave transmission across the English Channel in 1931 and directed the project which led to the opening of the world's first microwave radiotelephone link between England and France in 1934. Mr. Clavier has written on high-frequency radio communication and has taught field theory and applications of ultra-high frequencies at the Ecole Superieure d'Electricite in France.

He was made a Fellow of the American Institute of Electrical Engineers in 1953 for "pioneer work in research, development and engineering in the microwave field." He was chairman of the IRE's Professional Group on Microwave Theory and Techniques in 1953, "Membre Laureat" of the Societe Francaise des Electriciens, and a member of the Institution of Electrical Engineers of Great Britain.

(Continued on page 121A)

**Closing date for advertising
1955 IRE DIRECTORY
June 15, 1955**

I.R.E. People

(Continued from page 118A)

F. J. Gaffney has been appointed recently Vice-President for Engineering of Marion Electrical Instrument Company. In his new position he will direct the development of industrial and aircraft instrumentation.

F. J. Gaffney

Mr. Gaffney, well known for his work in electrical measurements, was formerly Director of Engineering for the Guided Missiles Division of Fairchild Engine and Airplane Company. During World War Two he served as head of the Test and Measurements group of the M.I.T. Radiation Laboratory, and, from 1945 until 1953, he was General Manager of the Polytechnic Research and Development Company.

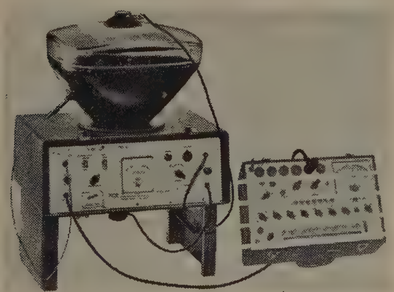
For a number of years he has served as a consultant to the Department of Defense and currently serves as a member of the Steering Committee of the Panel on Electronics in the Office of the Assistant Secretary of Defense for Research and Development. Mr. Gaffney is a member of the AIEE, American Physical Society, American Association for the Advancement of Science, U. S. Committee of the International Scientific Radio Union, Tau Beta Pi, and Sigma Xi.

News–New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 36A)

Portable Picture Tube Tester



In order to provide a complete, accurate test of the quality of a TV picture tube at a reasonable price, the Model 590 Picture Tube Tester, has been introduced by **Hickok Electrical Instrument Co.**, 10551 Dupont Ave., Cleveland 8, Ohio. The 590 permits an accurate check of the overall "light" efficiency of a TV picture tube, including brilliance, condition of phosphor, possible ion burns and probable life, and also permits an accurate check for emission, shorts, gas content, leakage and grid control.

(Continued on page 146A)

Positions Wanted

By Armed Forces Veterans

In order to give a reasonably equal opportunity to all applicants and to avoid overcrowding of the corresponding column, the following rules have been adopted:

The Institute publishes free of charge notices of positions wanted by I.R.E. members who are now in the Service or have received an honorable discharge. Such notices should not have more than five lines. They may be inserted only after a lapse of one month or more following a previous insertion and the maximum number of insertions is three per year. The Institute necessarily reserves the right to decline any announcement without assignment of reason.

ELECTRONIC—PRODUCT ENGINEER

BEE 1951. Age 33. 13 years in electronics. Design, development, production on fire and missile control radar systems. Video, servo, CRT, data transmission, system integration, human engineering. Liaison between engineering and production. Supervisory and some administrative experience. Self-starter and neck sticker-outer when expediency requires. Seeks position slightly over his head. Will relocate. Present income $9,000. Box 802 W.

(Continued on page 126A)

Positions Open

(Continued from page 143A)

ELECTRONICS ENGINEER

The U. S. Naval Postgraduate School has need for an electronics engineer in the computer laboratory for work with analog and digital computers. Opportunity to learn programming and coding and continue graduate studies. Electronics experience and mathematical interest necessary. Annual salary $5,060 to $6,940. Reply: Dept. of Mathematics and Mechanics, USNPS, Monterey, Calif.

POWER SUPPLY ENGINEERS

Graduate engineers with experience on tubeless regulated power supplies and magnetic amplifiers are needed. Write company complete resume, or phone Philip Diamond, President, Perkin Engineering Corp., 345 Kansas Street, El Segundo, Calif., ORegon 8-7215.

Deadline for ordering 1955 IRE Convention Record (complete text of papers delivered at the 1955 IRE Convention in New York, published in 10 parts)

is

April 30, 1955

Act Now!

DU MONT
Instrument Division

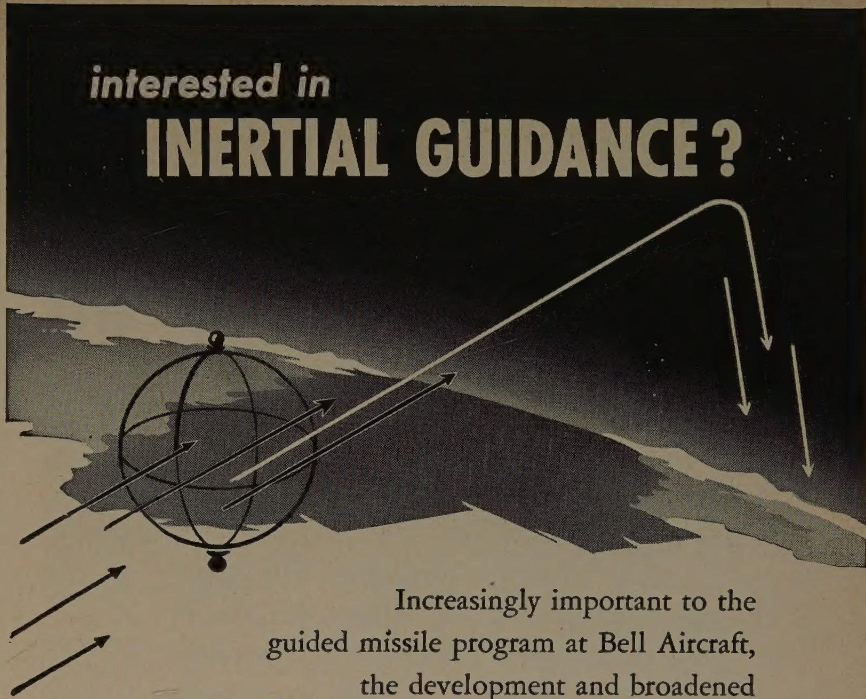
needs additional high calibre engineers for

- Electronic Instrumentation
- Missile Work
- Test Equipment
- Timing and Pulse Circuits
- Video Circuits
- Electro-Mechanical Devices
- Recording Systems

for both commercial and government output

Contact
Mr. George A. Kaye
Employment Manager

ALLEN B. DU MONT LABORATORIES, INC.
35 Market Street
East Paterson, New Jersey



Increasingly important to the guided missile program at Bell Aircraft, the development and broadened application of these and allied devices offers an opportunity and challenge to:

ELECTRONIC DEVELOPMENT ENGINEERS
including specialists in magnetic amplifiers, transistor circuits and airborne digital computer techniques to design and develop electronic components such as precise integrators, accelerometers, computers, feedback amplifiers, and instrument servos for use in inertial guidance.

SERVO SYSTEM ENGINEER
Analyze, design and develop complete systems for inertial guidance, with the help of a team of specialists.

SERVO VALVE DEVELOPMENT ENGINEERS
Design and develop high performance servo valves for autopilots in special aircraft, helicopters, and missiles.

To qualified personnel, these positions are well worth investigating. Get complete facts by writing (or sending resume') to: Manager, Engineering Personnel

BELL Aircraft CORPORATION

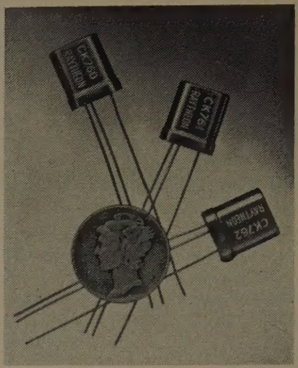
P. O. BOX ONE • BUFFALO 5, N. Y.

News-New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 121A)

Transistors



Raytheon Manufacturing Co., Receiving and Cathode-Ray Tube Operations, 55 Chapel St., Newton 58, Mass., announces three rf fusion-alloy germanium transistors, types CK760, CK761 and CK762 with alpha cutoff frequencies of 5, 10 and 20 mc, respectively. All are hermetically sealed and use a polarized lead arrangement for ease in socketing. Collector capacity for each type averages 14 $\mu\mu f$, and extrinsic base resistance for each is about 75 ohms. Further information may be obtained from Technical Information Service, Ratheon.

(Continued on page 149A)

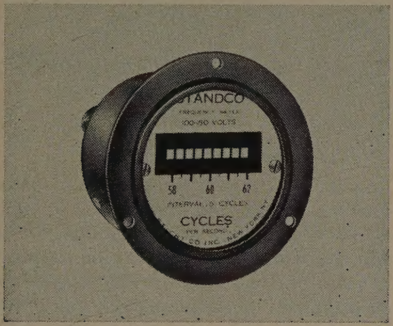
News-New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 146A)

New Meters

The Herman H. Sticht Co., Inc., 27 Park Place, New York 7, N. Y., announces their new line of 3½ inch flush panel mounting vibrating reed frequency meters, tradename, "STANDCO." These instruments are direct-reading frequency meters which are based on the principle of resonance. They consist of a number of steel reeds which are tuned to specific frequencies.



"Standco" panel frequency meters are made in 3 styles of cases, molded bakelite case, metal case and hermetically sealed case. They come with 5, 7, 9, 11, 21, 36 or 41 reeds for normal frequencies of 25, 50, 60 and 400 cps. Other ranges from 15–1500 cps can be supplied. Accuracy of calibration ±0.5 per cent. Request bulleting 805 from the manufacturer.

Gams Appointed by N. J. Electronics

N. J. Electronics Corp., 345 Carnegie Ave., Kenilworth, N. J., announces the appointment of Theodore C. Gams as Director of Research. He will direct the company's new development program in the field of electronic instruments.

Mr. Gams has been a consultant in industrial electronics, instrumentation, and radar equipment design for the past eight years. Previously he was a lecturer in applied electronics at the Polytechnic Institute in Brooklyn from 1945 to 1952.

(Continued on page 150A)

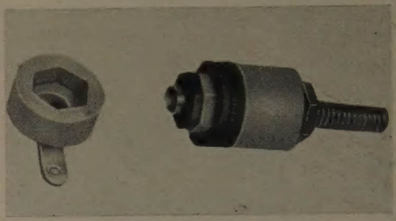
News-New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your I.R.E. affiliation.

(Continued from page 149A)

Hermetic-Seal Bushing

A new rivet-type, hermetic-seal bushing which meets MIL-T-27 specifications and conforms to the MIL-T-27 Twist Test, has been announced by the **Heldor Bushing & Terminal Co., Inc.,** through its sales agent **Heldor Manufacturing Corp.,** 238 Lewis St., Patterson, N. J.



Its insulation resistance, at 45 per cent relative humidity at seal level, is over 500,000 megohms. The manufacturers claim that these terminals can be supplied and installed at a lower price than solder seal terminals of equivalent rating. They further claim they will out-perform any terminal made today. These bushings are available in 5 standard styles, or can be modified to meet the customer's requirements.